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COMPARATIVE STUDY ON THE USE OF FIBRE OPTICS AND CONVENTIONAL CABLING SYSTEMS ON BOARD CCG VESSELS

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The contents of this report reflect the views of DTI Telecom Inc. and not necessarily the official views or opinions of the Transportation Development Centre and the Canadian Coast Guard of Transport Canada.

Un sommaire en français de ce rapport est inclus avant la table des matières.

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16. Abstract

This document describes a detailed comparative engineering and economic study of fibre optics with the conventional cabling techniques for eight target application areas on board CCG vessels.

Equivalent fibre optic-based systems to conventional cabling systems were designed. Each system was analyzed on a one-to-one fibre optic replacement basis and for its potential for integration.

Systems that offered good potential for integration were re-designed as part of an integrated ship-wide fibre-based local area network.

A comparative analysis of incremental costs applicable to both technologies only is presented. Costs common to both technologies were considered off-setting costs and are not part of the analysis. An analysis of market demand and pricing trends of fibre optics is also presented.

Conclusions and recommendations are presented for the use of fibre optics for marine applications on board CCG vessels in the short term and the mid-to-long term.

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16. Résumé

Il s'agit d'une étude comparative détaillée sur les avantages technico-économiques respectifs des réseaux de câblage à fibres optiques et des réseaux classiques à conducteurs métalliques, dans huit secteurs d'application différents à bord des navires de la GCC.

Les auteurs ont défini des réseaux à fibres optiques équivalents aux réseaux classiques en place. Chaque réseau a été reconstruit en procédant au remplacement conducteur par conducteur, puis on en a analysé les possibilités d'intégration.

Ceux des réseaux qui offraient une bonne possibilité d'intégration ont été réétudiés dans l'optique de l'extension d'un réseau local intégré à fibres optiques à l'ensemble du navire.

Le rapport présente une analyse comparative des surcoûts liés au choix de l'une ou l'autre des technologies considérées. Les coûts communs aux deux n'ont pas été pris en compte puisqu'ils peuvent être tenus pour s'équivaloir ou, en d'autres termes, s'annuler. Une analyse du marché des fibres optiques et de l'évolution des prix est également présentée.

Enfin, le rapport présente des conclusions et recommandations concernant les utilisations marines des fibres optiques à bord des navires de la GCC, aussi bien à court terme qu'à moyen et long terme.

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Fibres optiques, câblage en cuivre, interférence hautes fréquences, brouillage électromagnétique, intégration, automatisation, réseau local, réseau à fibres optiques, garde côtière canadienne, applications marines, systèmes de bord.	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

The major objective of this study was to evaluate the technical and economical viability of the fibre optic technology compared to the existing cabling techniques for a number of specific systems on board the Canadian Coast Guard vessels.

The study also had to determine whether fibre optics can be considered a suitable replacement for conventional cabling on board CCG vessels, as part of a given ship mid-life refit program. The potential to integrate some of the communications systems and other applications also had to be evaluated. The study provided a suitable framework of reference for comparing both the costs and configuration of fibre optic-based systems with copper-based systems.

Eight systems on board the Sir Wilfrid Laurier, used as a reference ship, were examined during the study: public addressing system, PBX, TV entertainment system, propulsion control system, fire detection system, alarm and monitoring control system, video surveillance system and gyrocompass system.

Firstly, each system was compared on a one-to-one basis with a fibre optic equivalent system configuration specifically designed for that purpose. Incremental costs of replacing the existing cabling with fibre optics were determined and compared. Equipment and labour costs common to both configurations were not considered. Advantages were noted in each case.

The results of the comparative analysis revealed that in all cases the fibre optic alternative is more expensive than the copper based equivalent system, on average by a ratio of 14 to 1. The fibre optic equivalent systems were designed with custom-made interfaces thus making the costs relatively higher than if these units were commercially available.

In the short term, the propulsion control system and the video surveillance system are the only systems identified as suitable candidates for the replacement of the existing cabling with fibre optics. This is based on the small cost difference between the copper and fibre configurations. With the propulsion control system, the fibre optic system would also eliminate certain problems caused by RF interference.

Secondly, the systems were evaluated using an integrated system approach. Four systems - public addressing system, PBX, fire detection system, alarm monitoring and control system - were found suitable for integration with a single fibre optic local area network (LAN) on board ship. The incremental costs of providing a fibre integrated network and the four systems integrated to it were also determined.

The other four systems - entertainment distribution system, propulsion control system, gyrocompass system and video surveillance system - were found better suited as autonomous systems.

The study also examined the trends of the fibre optic technology and its use for marine applications.

This technology has inherent characteristics - light weight, small size, immunity to electro-magnetic interference, high data transmission rate - which make it attractive for use on board CCG vessels, particularly as a solution to some of the transmission problems caused by radio interference and as an important element in the integration and automation of shipboard systems. The advantages in this case are a reduction in operational costs and improvement in the management efficiency of a ship.

Fibre optics is a mature technology that is already being used today on board some ships and is increasingly being considered for marine applications. However, we believe that the process of replacing existing systems on board ship by fibre optic-based systems will be a slow one; and, is more likely to occur with the introduction of new systems by manufacturers that will incorporate fibre-optic technology and components.

There is a strong industry movement to adopt Fibre Distributed Data Interface (FDDI) topology as a standard for the development of fibre optic LAN-based systems. This has a major implications on the development of fibre optic products and systems, sources of suppliers, support services and in the reduction in prices of material and equipment. The U.S. Navy cabling developments plans for the 1990's are based on the FDDI protocol and will have a significant impact on the use of fibre optics on board ships and the availability of standard interfaces at reasonable prices for shipboard applications.

We therefore believe that FDDI is the most appropriate technology to meet the mid-to-long term needs of the Canadian Coast Guard for a fibre optic LAN-based integrated system on board ships.

The main conclusions of the study were the following:

- Fibre optic systems are more expensive than the copper systems considered in the study.
- Two systems - the propulsion control system and the video surveillance system - are in the short term the best candidates for fibre optics implementation.

- Four systems - public addressing subsystems, PBX subsystems, fire detection system, alarm monitoring and control system - have good potential for integration with a fibre optic LAN backbone system.

- The process of replacing existing systems by fibre-based systems on board ship will be a slow one.

- The FDDI protocol is the most appropriate technology to meet the mid-to-long term needs of the Canadian Coast Guard for the integration of systems on board their ships.

The recommendations of the study are described bellow:

In the short term, the Canadian Coast Guard should:

- Consider the use of fibre optics for the propulsion control system and the video surveillance system, as part of a mid-life refit program.

- Continue experimenting with fibre optics by evaluating the technology under different environmental conditions and for the development of standards for its use on board ships.

- Ensure that the development of fibre optic-based systems and applications within the CCG be compatible with the FDDI protocol.

- Meet with the manufacturers of fibre optic-based systems for marine applications.

In the mid-to-long term, the Canadian Coast Guard should:

- Consider evolving towards an integrated system approach for shipboard systems.

- Consider introducing a fibre optic LAN backbone system as part of a ship's cabling infrastructure.

- Consider the development of fibre optic-based shipboard applications in accordance with the FDDI protocol.

SOMMAIRE

Ce document fait état d'une étude détaillée dont l'objectif principal est d'évaluer la viabilité technique et économique de la fibre optique par rapport à celle des techniques du câblage conventionnel de systèmes spécifiques à bord des navires de la Garde côtière du Canada.

L'étude devait déterminer si le câblage à fibres optiques peut être considéré comme une technologie appropriée pour remplacer le câblage conventionnel (câble multifilaire de cuivre) à bord des navires de la Garde côtière du Canada, dans le cadre d'un programme de réfection majeure des navires. Par la même occasion, les possibilités d'intégration de plusieurs systèmes de communications ont pu être évaluées.

L'étude propose un cadre de référence adéquat permettant de comparer les coûts et les configurations des systèmes de câblage à fibres optiques avec ceux des systèmes de câblage conventionnel.

À bord du Sir Wilfrid Laurier, considéré comme navire de référence, huit systèmes furent examinés dans le cadre de cette étude: système intégré de communications, sous-système de central automatique (PBX), sous-système de sonorisation publique, système de divertissement à bord, système de propulsion, système d'alarme d'incendie, système de supervision et de contrôle, système de surveillance vidéo, système de gyrocompas.

Dans un premier temps, chaque système fut comparé séparément à une configuration équivalente au câblage à fibres optiques, conçue spécifiquement pour l'exercice. Les coûts supplémentaires occasionnés par le remplacement du câblage actuel par le câblage à fibres optiques furent déterminés et comparés. Les coûts des équipements, du matériel et de la main-d'oeuvre communs aux deux configurations s'annulant mutuellement ne furent pas considérés dans l'analyse. Dans chaque cas, les avantages furent identifiés.

Les résultats de l'analyse comparative révèlent que les configurations équivalentes au câblage à fibres optiques sont, dans tous les cas, plus chères que les configurations des systèmes actuels, en moyenne dans un rapport de 14 à 1. Ceci est attribuable au fait que les systèmes de câblage à fibres optiques nécessitent des interfaces particulières qui sont indubitablement plus chères que si elles étaient disponibles commercialement.

À priori, le système de propulsion et le système de surveillance vidéo nous apparaissent comme étant les deux seuls systèmes qui peuvent avantageusement substituer le câblage actuel par du câblage à fibres optiques. Ceci est attribuable à la différence minime de coûts entre les configurations actuelles et celles du câblage à fibres optiques. De plus, dans le cas du système de propulsion, le câblage à fibres optiques permettrait de résoudre certains problèmes d'interférence radio.

Deuxièmement, les systèmes furent évalués en utilisant une approche visant l'intégration de systèmes. Ainsi, quatre systèmes, soit le sous-système de sonorisation publique, le sous-système de central téléphonique, le système d'alarme incendie et le système de supervision et de contrôle seraient plus aptes à être intégrés à un réseau local à fibres optiques installé à bord d'un navire. Les coûts additionnels d'installation de ce réseau à fibres optiques et d'intégration de ces quatre systèmes furent également évalués.

Par contre, les quatre autres systèmes, soit le système de divertissement à bord, le système de propulsion, le système gyrocompas et le système de surveillance vidéo n'offrent pas de facilité d'intégration et doivent préférablement être considérés comme des systèmes autonomes.

L'étude permit aussi l'examen des tendances de la technologie à fibres optiques et en particulier quant à son attrait pour les applications navales.

Cette technologie possède des caractéristiques intrinsèques - légèreté, dimension réduite, immunité à l'interférence des ondes électro-magnétiques, haut taux de transmission de données - qui la rendent attrayante pour des applications à bord des navires de la GCC. En particulier, elle représente une solution aux problèmes de transmission causés par l'interférence radio, une considération importante dans l'intégration et l'automatisation de systèmes à bord des navires. Dans ce dernier cas, les avantages anticipés prennent la forme d'une réduction des coûts opérationnels et d'une amélioration de l'efficacité dans la gestion du navire.

La fibre optique est une technologie parvenue à maturité, qui est déjà utilisée à bord de certains navires et est considérée de plus en plus pour des applications navales. Par contre, nous croyons que le processus de remplacement des systèmes actuels existant à bord des navires par du câblage à fibres optiques sera lent. Ce type de câblage sera plutôt introduit à même les nouveaux systèmes de remplacement qui seront offerts par les manufacturiers.

Il existe présentement dans l'industrie un mouvement pour faire adopter la topologie FDDI (Fibre Distributed Data Interface) comme norme de développement des systèmes de réseau local à fibres optiques. Ceci a des conséquences importantes sur le développement des produits et des systèmes à fibres optiques, l'offre des fournisseurs, les services de soutien et sur la réduction des prix du matériel et de l'équipement. Les plans de développement de la marine américaine (U.S. Navy) en matière de câblage pour les années 1990 sont basés sur le protocole FDDI et auront un impact considérable sur l'utilisation de la fibre optique à bord des navires et la disponibilité d'interfaces normalisées à prix abordables pour des applications navales.

Nous croyons que le protocole FDDI est la technologie qui répond le mieux aux besoins de la Garde cotière du Canada à moyen et long terme dans l'optique de l'établissement d'un réseau local intégré utilisant la fibre optique à bord des navires.

Les conclusions principales de l'étude sont les suivantes:

- Les systèmes de câblage à fibres optiques sont dans tous les cas plus chers que les systèmes actuels considérés dans le cadre de l'étude;

- Deux systèmes, soit le système de propulsion et le système de surveillance vidéo offrent à court terme un potentiel pour l'implantation possible du câblage à fibres optiques;

- Quatre systèmes, soit le sous-système de central automatique, le sous-système de sonorisation publique, le système d'alarme d'incendie, le système de supervision et de contrôle offrent un potentiel d'intégration à un réseau local à fibres optiques à bord des navires.

- Le processus de remplacement du câblage des systèmes actuels par du câblage à fibres optiques à bord des navires de la GCC se fera lentement.

- Le protocole FDDI s'avère comme étant la norme appropriée pour satisfaire les besoins de la GCC pour l'intégration de systèmes à fibres optiques à bord de ses navires.

Les recommandations de l'étude sont les suivantes:

À court terme, la GCC devrait:

- Considérer l'utilisation de la fibre optique pour les systèmes de propulsion et de surveillance vidéo, dans le cadre d'un programme de réfection majeure d'un navire.
- Poursuivre l'expérience d'utilisation de la fibre optique dans le but d'évaluer cette technologie sous différentes conditions d'applications et pour assurer le développement de normes d'utilisation à bord de ses navires.
- S'assurer que le développement de systèmes et d'applications utilisant la fibre optique au sein de la GCC soient compatibles avec le protocole FDDI.
- Rencontrer les manufacturiers de systèmes utilisant la fibre optique dans des applications navales.

À moyen et à long terme, la GCC devrait:

- Adopter une approche évolutive d'intégration de systèmes à bord de ses navires.
- Favoriser l'introduction d'un réseau de câblage à fibres optiques comme partie intégrante du câblage d'un navire.
- Normaliser le développement d'applications utilisant la fibre optique conformément au protocole FDDI.

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1. INTRODUCTION

1.1 PURPOSE

The present study was carried out at the request of the Transportation Development Centre (TDC) on behalf of the Telecommunications and Electronics Directorate (T&E) of the Canadian Coast Guard (CCG), by DTI Telecom Inc. (DTI) under contract with Transport Canada.

The Transportation Development Centre gave DTI the mandate to perform task # 11-JR, under contract # T8200-6-6509/01-AF, referred to in the statement of work as: Comparative Study - Shipboard Fibre Optics.

The overall objective of the study is to provide a comparative engineering and economic analysis concerning the use of fibre optics and conventional cabling on board CCG vessels for specified shipboard applications, with a view to reducing capital investment, maintenance costs and the risk of RF interference, while improving performance and bandwidth.

The work, as described herein, consisted in developing a suitable framework of reference for comparing the use of fibre optics for shipboard applications to conventional cabling, in order to determine if fibre optics should be considered as a potential replacement for conventional cabling of systems on board CCG vessels, as part of a given ship's mid-life refit program.

1.2 BACKGROUND

Shipbuilding activities are a major on-going concern of the Canadian Coast Guard. Whether it is for the construction of new ships or for the refit of existing vessels, an important part of the CCG planning activities and resources is devoted to this area. Of primary importance is the need for the continuous upgrading of the capability of the various systems and equipment on board CCG vessels with the latest proven state-of-the-art technology and equipment, for systems such as the monitoring and control, navigation and communication systems.

With some of its inherent characteristics - light weight, small size, immunity to electro-magnetic interference (EMI), high data transmission rate - fibre optics offers an interesting potential as a transmission media for its use on board GGC vessels and as an eventual replacement for conventional copper-based systems.

Thus, the T&E Directorate of the CCG identified a need to compare the fibre optic technology with conventional cabling techniques for specific shipboard applications to meet present and future requirements.

1.3 REPORT CONTENTS

This report is organized into four distinct parts, with nine chapters in all.

The first part establishes the context of the report and includes the introduction (Chapter 1), the terms of reference (Chapter 2), the methodology (Chapter 3) and a review of the study requirements (Chapter 4).

The second part (Chapter 5) is a review of technology and includes a discussion of some of the technology issues, a state-of-the-art review of fibre optics for shipboard applications and the identification of potential fibre optics applications for CCG vessels.

The third part consists of Chapters 6 and 7. Chapter 6 is a detailed technical comparative analysis of fibre optics with the conventional cabling techniques for each system considered for the study. A fibre optic integrated system approach is also presented for the systems identified as having a good potential for integration. Chapter 7 is a discussion of the financial and economic considerations with respect to the comparative technical analysis and the fibre optics trends.

The conclusions and recommendations are presented in the fourth and final part of the report (Chapters 8 and 9).

2. TERMS OF REFERENCE

The terms of reference for the study were developed by TDC and are presented as Appendix A of the report.

2.1 DETAILED STATEMENT OF WORK

The scope of this study is defined by the following detailed statement of work:

a) Carry out a survey of the requirements for point-to-point type and other networks on board CCG vessels for the following target application areas, by order of priority:

- internal communication system;
- entertainment distribution system;
- propulsion control system;
- fire detection control system;
- alarm and monitoring control system;
- video surveillance system;
- speed log and gyrocompass system.

b) Conduct a comparative engineering and economic study between conventional twisted-shielded pair/coaxial/4-wire media and the fibre optic alternative taking into account the economic, performance and operational issues;

c) Investigate the potential to integrate the individual systems identified above, as a result of the potential offered by using fibre optics and the resulting increase in bandwidth availability;

d) Study the interfacing issues related to each application and provide comments on the likelihood of integrating fibre optic electronics with the existing terminal equipment; and,

e) Prepare recommendations towards the use of fibre optics as a communication (or transmission) media on board CCG vessels for the selected systems (designated application areas).

2.2 STUDY CONDITIONS

The study was carried out under the following conditions:

a) The time frame envisaged for the replacement of the conventional cabling by fibre optics is the mid-life refit of a ship, usually about 15 to 20 years after the ship's commissioning.

b) The study does not consider the installation and integration of systems in the case of a new ship.

c) The designated target class of ships for the study is Class 1100. The Sir Wilfrid Laurier, the newest ship of the Laurentian Region fleet, was used as a reference for the study.

d) The information on the cost of the fibre optic material, equipment and labour was obtained primarily over the phone from suppliers without providing them with written technical specifications of the systems considered.

3. METHODOLOGY

3.1 STUDY APPROACH

The approach used by DTI to meet the study objectives was as follows:

a) Conduct background research which involved:

- becoming familiar with the CCG 1100 class vessel targeted for the study and the systems to be investigated, including a minimum of two visits on board the reference ship;
- gaining access to the reference information concerning these systems, including pertinent records and reports;
- obtaining information on the use of fibre optics in the transportation field and in particular in communications and control systems applications on board ship and aircraft; and,
- requesting information from suppliers.

b) Discussion with the TDC project officer and CCG personnel to confirm the study requirements.

c) Preliminary design of the equivalent fibre optic-based systems and preliminary comparison analysis based on the information available at the mid-point in the study.

Presentation of this information to the project team for evaluation and feedback as part of the first program review meeting.

d) Final design of the equivalent fibre optic-based systems and the potential integrated fibre optic system.

e) Comparative analysis of the equivalent fibre optic-based systems with the conventional cabling systems including cost, performance, operational data and potential for integration.

f) Discussion of findings with the project team as part of the second review meeting.

g) Preparation of the final report and presentation.

3.2 WORK ACTIVITIES

The work carried out by DTI included the following activities:

Phase 1

- Detailed work plan (approved by TDC).
- Review and analysis of reference CCG & TDC documents for selected systems.
- Literature search and bibliography.
- Request for information from suppliers.
- Follow-up telephone survey.
- Visit to Boston - conference and exhibits to meet with suppliers "Fibre Optic Systems for Mobile Platforms" technical session on shipboard applications (September 7, 1989).
- Visit of the Sir Wilfrid Laurier (June 28, 1989).
- Preparation of a technical status report (preliminary).
- Progress review meeting (Quebec City, September 28, 1989).

Phase 2

- Additional visit of the Sir Wilfrid Laurier (September 28, 1989).
- Detailed comparative analysis of fibre optics with conventional cabling:
  - Fibre optic equivalent configuration of each selected system for the study.
  - Costing information for each configuration using fibre optic and equivalent conventional cabling. Consultations with suppliers to confirm pricing.
  - Financial analysis - comparison of incremental costs.
  - Economic analysis - market demand and pricing trends of fibre optics from literature and discussions.
  - Conclusions and recommendations for each selected system and for a fibre optic integrated network.
  - Identification of other potential shipboard applications for CCG.
- Study conclusions and recommendations.
- Progress review meeting (Quebec City, November 2, 1989).
- Preparation of the final report and presentation.

4. REVIEW OF STUDY REQUIREMENTS

This section summarizes the study requirements and needs expressed by the representatives of TDC and CCG who were part of the project team, by way of the statement of work and completed through the various discussions held with them.

At the outset, it is important to note that the specific systems being considered for the comparative study were all independent systems and were designed, developed and installed on board ship in a unique way to meet the particular specifications and requirements of each individual system and particular ship and not in an overall integrated approach.

4.1 SYSTEMS REQUIREMENTS

For all the specific systems considered in the study, there is an overall requirement to determine the pertinence of fibre optics by providing for each system the following information:

- a fibre optic equivalent design to the specific conventional cabling system;
- a list of elements required;
- a summary of costs applicable to the fibre optic portion of the systems and the equivalent conventional cabling portion;
- performance data;
- advantages and benefits;
- potential for integration; and,
- timeliness of introduction.

For each specific system, particular requirements with respect to the applicability of fibre optics were suggested. A summary of these requirements is presented in Table 1.

Table 1 - Summary of Requirements for the Specific Shipboard Systems

System	Requirements
1. Internal Communication System	
a) Public Addressing Subsystem	Immunity to EMI - elimination of interference with the PBX and the Telephone Subsystem
b) PBX and Telephone Subsystem	Immunity to EMI - elimination of interference with the Public Addressing Subsystem
2. Entertainment Distribution System	Better quality of TV image - System elimination of interference of all signals on TV and FM bands
3. Propulsion Control System	Immunity to EMI - elimination of SCR triggering by radio frequency interference
4. Fire Detection Control System	Improvement in performance of the overall system and better resistance to fire and higher temperatures
5. Alarm Monitoring and Control System	Reduction in cable length and system weight
6. Video Surveillance System	Immunity to EMI
7. Gyro Compass System	Immunity to EMI and protection from changes in the magnetic field

4.2 PLANNING (FOR A MID-LIFE REFIT) REQUIREMENTS

The requirements for planning the mid-life refit of a ship, deciding on the work to be carried out and determining the appropriate funding for it are quite different in nature than the system requirements. This process usually involves considering a number of demands that normally exceed the planned budget allocation for the mid-life refit.

The decision to select and fund a particular project over another often results in a compromise between several potential scenarios. It is based primarily on the need to solve a particular problem or to satisfy an operational requirement and depends, to a large extent, on the costs involved.

With respect to fibre optic-based systems, it is important for those responsible for the planning of a ship's refit that the study address the following issues:

- the feasibility of replacing the conventional cabling for specific systems by an equivalent fibre optic - based system;
- the advantages and benefits involved;
- the costs involved;
- the impact that these changes may have for the CCG; and,
- the proposed strategy for the orderly introduction of fibre optic - based systems for shipboard applications.

4.3 FUTURE SYSTEMS REQUIREMENTS

The mid-life refit perspective of a recently commissioned ship such as the Sir Wilfrid Laurier is considered to be 15 years. It is also important that the study examine some of the future system requirements of the Canadian Coast Guard with respect to shipboard communication, monitoring and control functions.

As stated at the outset, all the systems studied were designed separately. The trend for the future may be towards the integration on a common transmission system of some of the ship's separate systems functionalities. This can be attributed in part to the fact that more digital systems are being introduced today and that some of the administrative, maintenance and communications functions on board ship are being targeted for automation. Digital systems and digital communications lend themselves better to the sharing of a common transmission media such as a local area network (LAN) backbone system using either a coaxial or a fibre optic cable.

With the introduction of a common or integrated transmission media on board ship it is expected that applications not envisaged today will be identified and introduced in the future. Thus, it is important to consider an adequate platform that will permit the development and integration of shipboard applications over time.

The overall bandwidth requirements of shipboard applications may not be an issue at the present time because of the fact that each system has been designed with its own dedicated transmission medium. However, future systems may be considered using an integrated system approach, thus placing a demand on the bandwidth availability of the common transmission media to be shared amongst systems.

5. REVIEW OF TECHNOLOGY

The purpose of this chapter is to provide a framework of reference to ensure that a common understanding is achieved with respect to the terms and concepts used throughout the study. It is not intended to be a comprehensive review of fibre optic technology and other study related concepts.

The use of fibre optics for marine applications was covered in several project reports prepared in the past for Transport Canada. These reports are listed in the literature survey.

The chapter is divided into two parts:

- Technology issues related to the study including analog and digital transmission systems, local area networks, fibre optics and system integration and automation; and,

- The use of fibre optics for shipboard applications including background studies, projects and a state-of-the art review material of and equipment.

5.1 TECHNOLOGY ISSUES

5.1.1 Introduction

Telecommunication is rapidly becoming the most common form of business communication. The transmission of data over cable or optical fibre is one of the most misunderstood points in telecommunications. It depends on several physical factors, such as distance, cable bends, cable gauge, external noise, cut-off frequency, multi-level coding.(1)*

Thus, a straight, short, low-gauge cable in a low interference environment can transmit tens of megabits per second, and be adequate to meet particular requirements.

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* Numbers in brackets designate references listed at the end of the report.

The choice of one transmission medium over another is not an easy one to make. The following notes are intended to provide a clearer understanding of the concepts and terms used in the technical analysis and hopefully, shed some light on some of the significant differences that must be considered when comparing the fibre optic technology with conventional cabling techniques for specific shipboard applications.

5.1.2 Fibre Optics

Fibre optics (2) is a fundamentally different transmission medium with particular properties that make it attractive for marine applications, that is, unlimited bandwidth with minimum loss and no EMI or RFI issues.

Fibre optics can more accurately be described as "lightwave" or waveguide optics. Fibre optics is a guided media (cable based) transmission technology with the properties of radio waves. The optical fibre is a strand of solid glass about the size of a human hair used to conduct light for communications purposes.

A transmission link based on optics will consist of the following basic elements: functionally, an electrical signal stimulates a device which emits a light, the source; the light travels down a waveguide, the optical fibre, and is received by a detector which creates a current reproducing the input signal. A certain number of passive devices are needed in between to connect fibres or to split and couple the light.

Optical fibres are currently used on transmission distances that range from a few centimetres to hundreds of kilometres with very small loss of signal and a significant signal to noise ratio.

The basic optical fibre consists of two concentric layers of glass:

- The core, the inner layer, serves as the medium for light transmission. The core has a higher refractive index than the surrounding cladding. It is usually coated with a substance to reduce losses and improve strength and flexibility.

- The cladding provides a lower refractive index in order to contain the light in the core to facilitate transmission down the fibre, it also protects the fibre against bends and strains.

Fibres are usually classified by their refractive index profiles and their core/cladding sizes.

There are three main types of fibres: multimode step index fibre, multimode graded index fibre and single-mode fibre.

A single fibre of 625 um (core)/125 um (cladding) is the type used in this study.

The attenuation or power loss (the decrease of signal power with distance in the fibre, expressed in dB/km) is normally proportional to the length of the fibre and inversely proportional to the wavelength. Wavelengths of: 780-850nm, 1310nm, and 1550nm, or lowest loss, are used.

The bandwidth of a fibre can be defined by the highest frequency signal which may be effectively transmitted, and thus is a measure of the information carrying capacity of the fibre. It is measured at the half-power point (-3dB). For fibre specification, it is referenced to one km, and expressed in MHz/km.

A passive device is an optical component which does not require active powering for operation such as connectors, splitters, couplers and the fibres themselves. They generally have excellent temperature and lifetime characteristics but introduce some loss in the system.

Two different types of connection can be performed in an optical link: for a removable connection, a connector will be added; for a permanent connection, a splice will be done.

Three main types of splices exist in order to connect two fibres: fusion splices, mechanical splices and vee-grove splices. Fusion splices are the best, but are more difficult to perform. Mechanical splices are more flexible and require less training and sophisticated equipment. Vee-grove splices, without fusion, are very fragile and have to be ruggedized with strength members.

Connectors are used to link the fibre to any device, when splicing is not desired. They are removable, thus adding flexibility to a link. Couplers are bidirectional devices used to combine or split the light from/to two or more ports.

Wavelength division multiplexing (WDM) allows the transmission of different signals, modulated on different wavelengths, on the same fibre, thus increasing the capacity of fibre links and adding to the network flexibility.

The price of equipment at the transmit end is usually much higher than that at the receiving end. This comes partly from the difference of complexity and price between light sources and detectors. Both are active devices, meaning, that they require active powering for operation.

The perfect optical detector would be sensitive, quick, small, of low cost, insensitive to the environment and of low noise. Other active devices include external modulators, optical switches and optical amplifiers.

Fibre optics is particularly attractive and offers numerous advantages over existing cabling for shipboard applications as shown in Table 2.

Table 2 - Advantages of Fibre Optics for Shipboard Applications

Property	Advantages
Small size	reduction in cabling size, weight, space requirement, cable pulling
Light weight	reduction in cabling weight, cable pulling
Immunity to EMI, RFI	noise free transmission, better reliability of systems, safety improvement, elimination of cross-talk, security of transmission
Electrical isolation	safety improvement, reduction in spark/fire hazard, elimination of ground loops
Unlimited bandwidth	optimal capacity for transmission requirements
No loss of signal	significant signal to noise ratio,improvement in reliability of systems
Resistance to water and moisture	safety improvement
Resistance to high temperature	increased reliability of sensors, safety improvement

5.1.3 *Fibre Optic Transmission System Considerations - Analog vs Digital*

Analog modulation (amplitude and frequency) and digital modulation systems are the choices available today with fibre optic systems. Both types of modulation are used by the existing system on board ships.

In digital modulation, the signal quality is measured as the Bit Error Rate (BER), which defines the error ratio on the recognition of the coded signal at the reception. The most common value taken as reference is 10^{-6}. There is a correspondence between BER and the Signal to Noise Ratio (SNR) as it is used in analog modulations for signal quality measurements, along with the carrier to noise ratio (CNR).

AM modulation is bandwidth efficient, requiring only 6 MHz as in the case of a video channel for instance, compared to FM modulation which is not very bandwidth efficient with at least 30 MHz required by video channel.

FM transmission presents by nature much greater immunity to noise and transmission impairments. The overall signal quality is much easier to achieve.

Digital transmission is a type of "non-linear modulation". The advantages of digital transmission for marine applications can be stated as follows:

- uniform performance unaffected by transmission distance or system configuration;
- no signal degradation when regenerated;
- significant design and component advances;
- low maintenance costs;
- configuration flexibility;
- supply of commercially available products for audio, video and data transmission;
- excellent basis for the development of future applications; and,
- good potential for integration to a common transmission medium.

The main drawbacks are:

- small video channel capacity per fibre, compared to analog. The bandwidth requirements are bigger than in FM;
- incompatibility in equipment from different manufacturers, because of the differences that occur in the implementation of coding schemes for instance.

To transmit voice over a digital link requires the signal to be digitized. The most common method of digitizing voice is called pulse-code modulation (PCM). In today's telephone network, voice is limited to 4 kHz; with PCM, voice is digitized by sampling voice signals at a rate twice the effective bandwidth or at a data rate of 64 kilobits per second. A T-1 link for example, which is the telephone industry standard for interconnecting digital communications systems, operates at a data rate of 1.544 megabits per second or the equivalent of 24 telephone circuits.

This factor will be important when evaluating the bandwidth requirements of the systems on board ships.

5.1.4 Local Area Networks (LANs)

A LAN is described as a network which connects together computers for data communications and usually spans a limited geographical area[3].

A LAN allows users to share information and computer resources, including mass data storage, backup facilities, software, printers, plotters and processors.

The primary need that must be satisfied by LANs is the requirement for connectivity. Connectivity or topology is defined as the ability to interconnect several devices that may have diverse communications protocols and speed.

The two most common topology arrangements are the bus and the ring, although the tree and star topologies are also available.

The bus topology involves a linear, usually continuous medium where all units attach directly, often by tapping. Each station transmits and receives signals on this commonly shared medium, following the access method protocols for the network.

The ring topology connects each station to the ones preceeding and following. This results in a continuous, closed path, upon which signals circulate throughout the network, usually in one direction. Thus a ring is a series of point-to-point links.

LANs display the following characteristics:

- continuous physical connectivity, but discontinuous logical connectivity;
- dynamic allocation of bandwidth to accommodate users' demands;
- traffic flow control so that each user receives some allocation of the total communications resources;
- protocol conversion to permit communications between dissimilar devices; and,
- immediate delivery of data; LANs do not store and forward messages like packet switching networks.

LANs can use different types of cabling as a networking medium to interconnect stations:

- Twisted pair cable is inexpensive but, in most cases, limits performance through low data rates, about 1Mbps. It can reach 10 Mbps over limited distances. Specialized provisioning can extend data rates, but with certain limitations.

- Coaxial cable, used in 90% of today's LANs has acceptable bandwidth - from 10 Mbps to more than 100 Mbps over limited distances - to match the capabilities of system components. However, it is relatively expensive. Triaxial and other forms of shielded control-impedance cable are also used to interconnect stations.

- Optical fibre represents an area of high growth and decreasing costs, with high performance driving the technology. Because of the short distance involved in LANs, multimode fibre is finding an immediate application. Many cost effective configurations for LAN application can justify installing optical fibre in buildings, campuses and even on board ships particularly as a backbone network.

5.1.5 System Integration and Automation

The best indicator of external pressure to integrate voice and data communications is the growth in data communications. If the current growth rate for data communications is extrapolated to the turn of the century, it will equal voice by 1992 and will occupy a majority of all communications by the year 2000.(3)

There are some problems in the evolution of today's telecommunications systems. First, because many applications are specific, especially automated systems, they tend to replicate many work or business applications. When voice and data systems grow independently, this translates into multiple communications lines and terminals at the same location.

Secondly, discrete applications-oriented systems tend to require conversion re-entering of information from system to system. Frequently, the same information is duplicated in several databases or files.

Communications can contribute to solving some of these problems by providing interfaces to move information efficiently between systems.

With machines that are proven more efficient at moving information than people, the objective is then to bridge the gaps in the level of automation already available with the systems in place.

The transmission medium is perhaps the most easily integrated network component.

A properly integrated voice/data system should imply that the information be input only once in order to deliver multiple outputs in multiple formats when and where required.

Involving people in the communication paths is usually very expensive. When a system is properly integrated, the indirect costs of people intervention should decrease dramatically and operational effectiveness can be achieved through automation.

This could translate into a potential reduction in the level of maintenance personnel required and in the ship's operating costs.

In fact, one of the benefits achieved by automation and integrated control is the unattended control of machinery spaces.

Another benefit, particularly with a fibre integrated LAN, is the reduction in weight of equipment and cabling which usually translates into savings in fuel consumption and a reduction in the ship's operating costs.

There is no doubt that fibre optic systems offer a great potential in the implementation of efficient, integrated ship operations, with considerable benefits.

The exact time to consider integration varies widely depending on the business and situation. One factor influencing the decision to integrate should be the readiness of the industry and the status of standards for the supply of the different components required for integration.

The main reasons to integrate voice, data and ship control functions are to reduce operational costs and to improve the management efficiency of the ship. Another reason to consider the integration of some of the systems on board ships for instance, is to provide the captain or the ship's officers with a clear and understandable picture of the operational environment at all times, coupled with a capability to maintain control in crisis or damage situations.

The trend towards digital systems is also an important consideration for integration. Many systems on board ship today are using digital coding as a basis for the processing and communication of the data. This facilitates the transfer and routing of data between systems and provides better noise immunity and the capability for multiplexing.

New applications can also be developed more easily, rapidly and probably at less cost with an integrated system approach using a standard backbone network interface already in place.

Any new network approach should improve reliability, flexibility and responsiveness to adjustment and changes. Systems that can adapt quickly and provide a common human interface will eventually be preferred over multiple, dispersed and monolithic structures.

Finally, there is also a continuous trend occurring today towards automating the information flows within organizations, including ships which have a requirement to have access to real-time information systems on a continuous basis.

5.2 FIBRE OPTICS FOR SHIPBOARD APPLICATIONS

This section outlines current activities related to the use of fibre optics and includes a state-of-the art review of fibre optic material and equipment for shipboard applications. The information was obtained from articles published in trade journals and conversations with some of the players in this field.

5.2.1 Review of Fibre Optics Shipboard Applications

5.2.1.1 Naval Installations

The United States Navy is planning to install the Survivable Adaptable Fibre Optic Embedded Network or SAFENET II counterrotating ring bus system, conformed to the FDDI proposed standard, as the ship data backbone network of the future. On board the aircraft carrier USS Saratoga, multimode fibre optic cable will interconnect four combat information centres.(4)

To accomplish the SAFENET II mission, the U.S. Navy has contracted the services, products and expertise of several manufacturers including: AT&T Federal Systems, Loral/Rolm Corp., Unisys and Martin Marietta.

The U.S. Navy is also reportedly planning more SAFENET II installations. The Naval Sea Systems Command (NAVSEA) is said to be considering the installation of SAFENET II on the new DDG-51 Arleigh Burke class of guided missile destroyers. More than a dozen of these destroyers are scheduled to be built over the next five years.

Since 1983, Litton's fibre optic facility has been developing an all-fibre-optic damage control system for shipboard applications. One such prototype system has been operating aboard the USS Mobile Bay CG-53 since 1987. To enhance this system, Litton has been designing in SAFENET I or II capability.

In addition, the Litton Data System Engineering Centre in concert with Litton's Ingalls Shipbuilding, is pursuing the development of a generic all-purpose SAFENET II local area network.

This LAN is aimed at many military applications, including the efficient transfer of combat system and navigational information.

The SAFENET program manager for the U.S. Navy sees the eventual need for SAFENET on board every ship of the Navy, because SAFENET is one of the ship data backbone architecture of the future. Because of SAFENET's OSI architecture, it is possible to pull out a card and plug in an upgraded one. He also expressed a desire to move away from military hardware as an exclusive requirement, in order to benefit from commercial non-military development in this area and to procure fibre data buses on board ships.

A summary of the fibre optic applications in the U.S. Navy is provided in Table 3.

Table 3 - U.S. Navy Fibre Optic Applications

Ship	Date	Application
USS Saratoga, Aircraft Carrier	1990	SAFENET II Combat Control System
USS Arleigh Burke, DDG-51 Class	no date yet	SAFENET
USS Mobile Bay, CG-53 Class	1987	Damage Control
USS Yorktown, AEGIS Cruiser	1985	Tank level, Damage Control Combat System
USS Valley Forge 1985		ICCS and LOCOP remote monitoring
USS Norton Sound, AVM-1	1983	ICCS and F/O motor
USS Wainwright -		TACAN antenna link
USS Kitty Hawk, Aircraft Carrier	1979	CCTV
USS Little Rock 1979		Telephone System

In Canada, in the late 1970's, the Department of National Defence recognized the need to update the Canadian Navy's ships with a fleet of the most advanced combat vessels to patrol Canada's coast line and carry out its anti-submarine warfare (ASW) responsibilities under the NATO agreement. It introduced the Canadian Patrol Frigate Program (CPF) and negotiated with Sperry Corp., now UNISYS Defence Systems, for the required highly specialized technical assistance for this project.(5)

An integrated combat system had to be designed to detect, identify and analyze multiple targets and to recommend and execute appropriate action within a matter of seconds. All subsystems involved in the defensive capability of the ship - sensors, weapons, electronic warfare, internal/external communications - had to be integrated into the overall combat system.

The Unisys SHINPADS Serial Data Bus (SDB) is used for these ships. It is a high speed inter-processor communication network designed for applications which require exceptional availability in diverse environments - mobile, ground, shipboard, fixed site or platform.

The three major elements of the SDB include the bus transmission system, interface set and user computer software. It was developed for use with coaxial cable but was examined for use with fibre optics as well, by replacing the SDB main bus with an optical bus topology.

SHINPADS can provide up to 9.5 Mbps of real data throughput for up to 256 users and has built-in test and monitoring system reconfiguration.

As part of the CPF program, CAE of Montreal, best known for its flight simulators, expanded into marine machinery control systems to supply some of the CPF requirements. SHINMACS was introduced for the integration of ship machinery and control systems. Information on SHINMACS was requested but could not be obtained.

In the late 1970's a fibre optic prototype system for a 35 channel communication system was installed at CFB Halifax Fleet School as part of the DDH-280 simulation environment.

5.2.1.2 Other Countries

There are relatively few installations on board non-military ships in other countries. The scope of these applications is far less considerable than the SAFENET program that is being developed for the U.S. Navy.

A summary of these installations is provided in Table 4.

Table 4 - Fibre Optic Applications in Other Countries

Country	Ship	Date	Application
Japan	America Maru	1981	Engine Control, Data Bus
Japan	Senho Maru	1985	Data Bus, Voice Communications, Video Surveillance, Engine Control
Germany	RV Polar Star	-	Data Bus
Australia	Submarine	1988	Damage Control, ICCS, Communications System
Holland	Frigate	1988	Combat System

The installation of fibre optics on board the America Maru was the first commercial fibre optic transmission system installed on a vessel in regular marine use. This application was described in a report prepared for TDC in 1983 (# TP 4840E).

5.2.1.3 Canadian Coast Guard

The Canadian Coast Guard became interested in fibre optic technology in the early 1980's. A study was carried out by Seimac Ltd. on the application of fibre optics to marine transportation (6) and by Focal Marine Ltd. on the development and testing of a fibre optic data system for marine transportation.(7)

The Focal Marine study was aimed at performing certain environmental tests of fibre optic components and subsystems with the objective of drafting a set of preliminary standards for marine use.

Currently, there is a pilot project being carried out in Dartmouth, Nova Scotia on board the William Alexander, with the participation of Focal Marine Ltd., as part of an experiment dealing with the integration of shipboard information management systems.

The project consists of a fibre optic LAN using an Ethernet topology. Details on the project were requested.

The Communications and Computers Division (AMTE) at CCG headquarters has also addressed the issue of LANs for use within CCG organization and have selected the token ring LAN for CCG office use.

The DTI study is the latest initiative in determining the applicability of fibre optics for CCG shipboard applications.

The DTI study deals with the topology, the protocols and the physical interfaces of specific shipboard subsystems and related costs. The scope of this study is quite different than the one of the Focal Marine study, which did not have to consider the topology of the system bus, analyze the various subsystems involved and determine the system costs. Both studies are complementary.

5.2.2 *Material and Equipment - State-of-the-Art Review*

5.2.2.1 *Shipboard Cables*

Status:

The fibre optic cable design (8) for a shipboard environment was developed primarily in the United States. Cable specifications exist (MIL-C-85045) and cable can be routinely purchased for ship installation.

The cable characteristics are the following:

- available in 2, 4 and 8 fibre configurations
- low smoke and toxic gas generations during fire
- can be installed along with copper cable with only the usual precautions for handling small diameter cables

Problem:

On a circuit - for - circuit basis, the purchase cost of fibre optic cable is higher than for copper cable ($ 3/m. for a 2-pair # 16 copper cable, $ 8/m. for a 2-fibre 62.5/125 micron cable).

Challenge:

The challenge is to reduce the cost of fibre optic cable.

Trend:

There is a downward trend in the cost of shipboard cables.

5.2.2.2 *Cable Connectors*

Status:

Past ship installations in the United States have used Amphenol type SMA single - channel connectors and Hughes MIL - C - 28876 multi-channel connectors.

Multi-channel connectors are available in straight, 45° or 90° backshell configurations.

A recent transition has been to AT&T ST single-channel connectors to military specification DOD - C - 83622.

Problem:

The connectors available today are relatively difficult to install under harsh conditions in the field. Loss per connector is still high (< 1dB).

Challenge:

The challenge is to develop connectors that are easier to install in harsh conditions and that offer low loss.

Trend:

The quality of connectors is rapidly improving.

5.2.2.3 Junction Boxes

Status:

Junction boxes are used for connecting cables and as a breakout point for cabling.

Junction boxes have been developed for rugged shipboard environments:

- shock qualified to MIL - S - 901C
- standard U.S. Navy drawing exists
- dozens have been purchased and installed

NAVSEA specification will provide for improvements in the box design.

Problem:

Fusion splicing cannot be accommodated in the current configuration. The access to individual mechanical connectors is difficult. The connector installation on a fibre is difficult in a junction box.

Challenge:

The challenge is to improve the manoeuvrability of junction boxes with fibre optics. The new NAVSEA specification incorporates improvements that are intended to resolve the problems identified above.

5.2.2.4 *Transit Devices*

Status:

Transit devices are used for penetration through bulkheads and into watertight enclosures.

Fibre optic cables have been tested using bulkhead stuffing tubes and the multi-cable transit device used in modern ships. Both types work well.

Problem:

There is no problem identified with the devices.

5.2.2.5 *Cable Repair Procedures and Hardware*

Status:

Cable repair procedures and hardware have been developed and were implemented aboard a U.S. military ship in early 1987.

Splicing was accomplished using SMA connectors and other specialized mechanical splices.

The primary upgrade since this first implementation is the use of the AT&T rotary splice for mechanical splicing.

Problem:

The cable emergency repair time (approximately 30 minutes) is critical and needs to be as short as possible.

Challenge:

The challenge is to develop better splicing techniques and devices that can reduce repair time and at same time can restore the mechanical integrity of the cable.

The evaluation of fusion splicing techniques to complement or replace mechanical splicing is also of concern.

5.2.2.6 Test Equipment

Status:

The basic test equipment includes the optical time domain reflectometer (OTDR) and the optical power meter.

Problem:

OTDR's for short distance measurements are needed and not readily available.

Power meters need better standardization.

Challenge:

The challenge is to develop OTDR's for short distance measurements that have better resolution and accuracy, better repeatability and standard calibration techniques. Also, there is a need to develop standards for power meter calibration.

5.2.2.7 Mechanical Switching

Status:

Fibre optic systems will require several types of mechanical switches: toggle, push button and rotary. Development work has been done and each type of switch is available in some form or another.

Problem:

The existing switches are either still somewhat crude or lack the robustness for ship application. They are not yet standardized for military specifications.

Challenge:

The challenge is to continue the development of mechanical switches in order to decrease insertion losses, improve reliability, lower costs and improve ruggedness for shipboard application. The improvement of the performance to cost ratio is an issue of concern.

5.2.2.8 Sensors

Status:

Sensors have been developed for the U.S. Navy ships.

Experimental sensors - smoke, fixed temperature (switch), temperature rate of rise, flood and torsionmeter - have been installed on the CG53 in February 1987 and are still operating satisfactorily.

All require additional reliability and accuracy testing. Some require design enhancements.

Other sensors - flame, analog pressure, analog temperature, proximity - exist, but require additional development work and test and evaluation.

Problem:

The high cost and slow development in this area are a problem.

Challenge:

The challenge is to improve the variety and quality of the sensors and to reduce costs.

5.3 OTHER POTENTIAL FIBRE OPTICS SHIPBOARD APPLICATIONS

The focus of this study is the use of fibre optics in the areas of machinery control, alarm and monitoring control and telecommunications. The integrated approach, the area of computer communications, and the exchange of data between systems using a common transmission medium are also explored.

The area of computer communications appears to offer the greatest potential for the development of new applications and for the automation of shipboard functions. Common to all the methods envisaged for the automation of ship control is the desire to concentrate control functions centrally and to reduce the size of the crew required.

For this to happen, the systems must be linked together to a central control computer function in such a way that they maintain their autonomy and remain unaffected by problems that may occur in another system.

The following data interchange applications can be envisaged:

- distribution of monitoring and control functions throughout the ship;
- remote maintenance diagnosis using an intelligent work station;
- management information systems (automatic updates, access to key result indicators, development of reports, ...);
- remote access to internal and external databases (material lists, documentation, records, library, ...);
- electronic information services (E-Mail, facsimile, billboard, EDI, ...);
- ship log information;
- information system for navigation (index of maps, access to data base of navigation or passage plans, access to actual maps, ...);
- video surveillance and audio/video playback system for operational and entertainment purposes (real-time recording, access to video tapes and compact disk library, ...).

6. COMPARATIVE ANALYSIS (COPPER VS FIBRE)

6.1 METHODOLOGY

The existing copper-based shipboard systems considered in this study have different topologies and use a variety of integration techniques substantially different from each other. As a result of these differences, the replacement model of the existing transmission systems with fibre optic cables has been analyzed according to the following guidelines:

- The existing transmission systems are redesigned on a one-to-one basis using fibre optics. When the fibre optic interface unit is known to be commercially available, the supplier and list price unit type have been indicated. When the replacement interface unit is not known to exist, the cost of the customized unit has been estimated based on the reference information available. A TBD (to be developed) tag marks these components in the costing tables.

- Each individual system is analyzed from two perspectives: one-to-one fibre replacement basis and potential for integration.

- Individual systems that offer potential for integration are re-designed as part of an integrated, ship-wide, fibre optic-based Local Area Network.

6.2 ASSUMPTIONS

- *Scope of implementation*

  The fibre optic systems considered in this report are assumed to be scheduled for implementation at the mid-life refit of a ship. Accordingly the ship is fully open to facilitate cabling and equipment installation. This is reflected in the estimate of labour costs.

  The Sir Wilfrid Laurier ice-breaker has been used as the reference ship for design and calculation purposes. Cabling topology and equipment configuration are based on the analysis of the ship's circuit drawings.

- *Copper/fibre replacement basis*

  For estimating costs the following general assumptions have been taken into consideration:

  - The central control unit and the terminal, or peripheral equipment, particular to each system are considered the same under both copper and fibre-optic configurations, unless otherwise specified.

    The cost of this equipment for one configuration is assumed to be off-set by the same cost for the other configuration. Therefore, the central control unit and the peripheral equipment are not included in the comparative analysis.

    Only the links (fibre or copper) connecting these units and their associated costs are considered.

  - The costs identified for the copper alternative relate to all the materials and labour required to replace the existing cable with new copper cabling.

  - The costs identified for the fibre optic alternative relate to all the materials and labour required to replace the existing cable with fibre optic cables.

  - The costs for materials and labour that are considered common to both technologies have not been included in the estimates. Only incremental (or differential) costs applicable to both technologies are accounted for in the comparative analysis.

  - The maintenance costs for the cabling in both cases are considered nil.

  - The costs for cable pulling (per cable) and cross-connects are considered the same for both copper and fibre optics.

- *Materials and labour cost assumptions*

  - Labour cost = $ 60/hour for a qualified technician

  - Copper cable and interface testing: 0.6 man-hour per terminal station

  - Fibre optic cable and interface testing: 1.2 man-hour per terminal station (speaker, sensor, etc.). On average, a 2:1 ratio is used for fibre optic testing.

  - Splicing: the time required to perform a mechanical splice is 15 minutes or .25 man-hour.

  - Connector fitting: the time required to fit and polish an ST connector is 15 minutes or .25 man-hour (curing time is 30 minutes or .5 man-hour).

  - Materials

    - two-fibre cable for marine use: $ 8/m.
    - four-fibre cable for marine use: $ 11/m.
    - two-fibre plus two-pair hybrid copper cable: $ 10/m.
    - dimension of fibre used is 62.5/125 microns, multi-mode responding to marine specifications.

6.3 ONE-TO-ONE FIBRE REPLACEMENT - COMPARATIVE ANALYSIS

6.3.1 Internal Communication System - Public Addressing Subsystem

6.3.1.1 Technical Comparison

The existing subsystem (Figure 1), assembled and partly manufactured by KWA (United Marine), consists of several multi-point lines connecting a series of speakers to the central equipment and the radio room.

One-way speakers use two # 18 wires while talk-back speakers use three # 18 wires. There is a total of 60 speakers on board with 45 (75%) of them being talk-back (microphone plus speaker assembly).

Each copper run of the existing subsystem has been replaced with one fibre plus one copper pair required to provide power to the fibre-audio interfaces (Figure 2).

Wave division multiplexers are used to provide a return channel for the talk-back speakers.

Using a transmitter LED with a launch optical power of -18 dBm and a receiver with -39 dBm sensitivity, a power budget of 15 dB is obtained as follows:

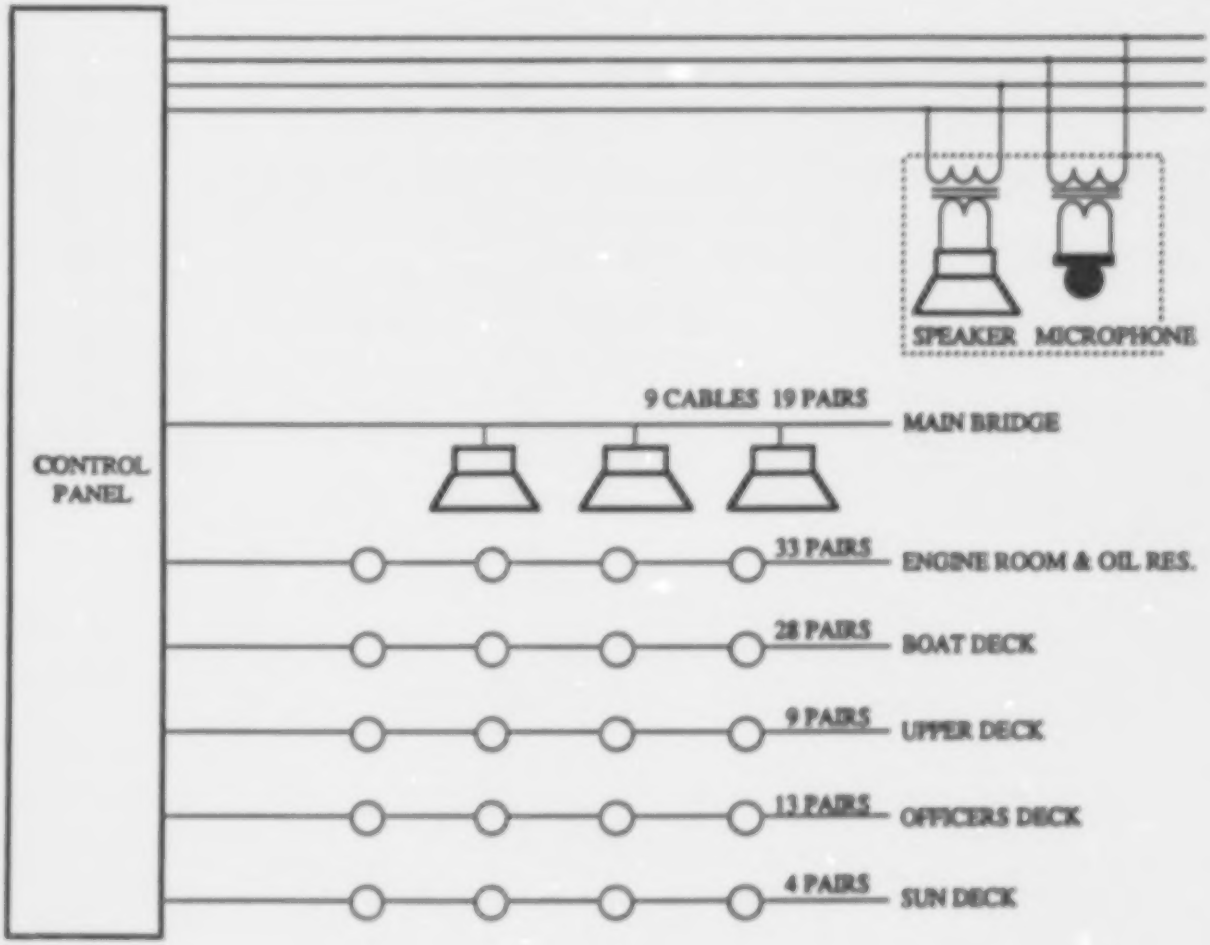
Power budget (B)	=	[Po (min) -Pi (min)] - m
Po	=	-18 dBm
Pi	=	-39 dBm
M (margin)	=	6 dB
B	=	15 dB

Each splice introduces 0.1 dB loss (average)
Each coupler introduces 0.2 dB loss (average)
The fibre attenuation is 0.2 dB/100 m.

Therefore we can estimate a maximum total loss of 0.5 dB per coupler.

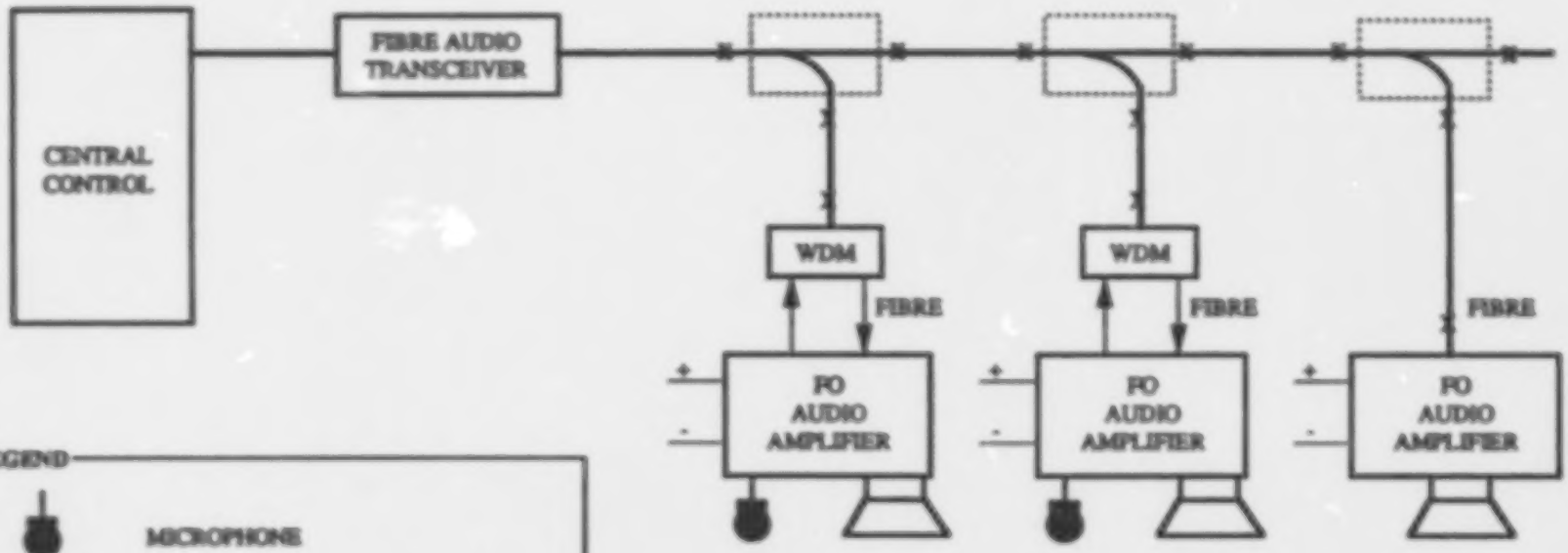
For a fibre run of 10 couplers (10 speakers), the total attenuation is 5 dB, allowing an additional 10 dB margin.

Figure 1. Public addressing subsystem - Copper installation



TOTAL CABLE LENGTH: 4440m
TOTAL CABLE WEIGHT: 888Kg
TOTAL NR OF SPEAKERS: 60
PERCENTAGE TALK-BACK: 75%

Figure 2. Public addressing subsystem - Fibre one-to-one replacement



LEGEND

- MICROPHONE
- SPEAKER
- X — SPLICE
- WDM — WAVELENGTH DIVISION MUTIPLEXER
- OPTICAL COUPLER

POWER BUDGET

B = [Po (min) - Pi (min)] - m
Po = -18dBm
Pi = -39dBm
m = 6dB
B = 15dB
SPLICES PER RUN = 22
COUPLERS = 10
MAXIMUM ATTENUATION = 10 x 0.5 = 5.0dB

6.3.1.2 Cost Comparison

The incremental costs associated with both systems are presented in Tables 5 and 6 as part of Appendix B.

The incremental cost of completely re-wiring the copper PA subsystem is estimated at $ 15,480.

The incremental cost of replacing the copper wiring of the PA subsystem with fibre optics is estimated at $ 210,710.

The cost of labour related to the installation of bulkhead penetrations and cross connects as well as cable pulling is assumed to be the same for both systems and, therefore, the incremental cost is considered nil.

6.3.1.3 Conclusions

The fibre optic-based subsystem offers better noise immunity than the copper subsystem. However, it is more expensive and does not necessarily reduce the weight of the existing copper installation, since remotely-fed power is required for the speaker interfaces.

6.3.2 *Internal Communication System - PBX Subsystem*

6.3.2.1 *Technical Comparison*

The existing subsystem (Figure 3) is based on a star configuration with each telephone connected point-to-point to the central Mitel SX-20 PBX (analog).

Several telephones, specially manufactured by KWA are multi-line sets equipped with key-activated features and lines.

A total of 38 telephone sets are connected to the PBX using two-pair shielded # 18 cables (Belden 9368).

Crosstalk between the ship radio system and the PBX system has been occasionally experienced.

A fibre optic-based installation would solve this and other problems associated with the analog PBX system.

The proposed fibre-based design (Figure 4) consists of an optical patch panel located in the communications room and hybrid cables (one fibre plus one copper pair for power) that will link the telephones to the PBX. Optical interface units for telephone loops are not currently available, so a customized interface must be ordered from an outside firm. The phone system to be installed during the refit process is assumed to be digital to minimise the hardware complexity.

Figure 3. PBX subsystem - Copper installation

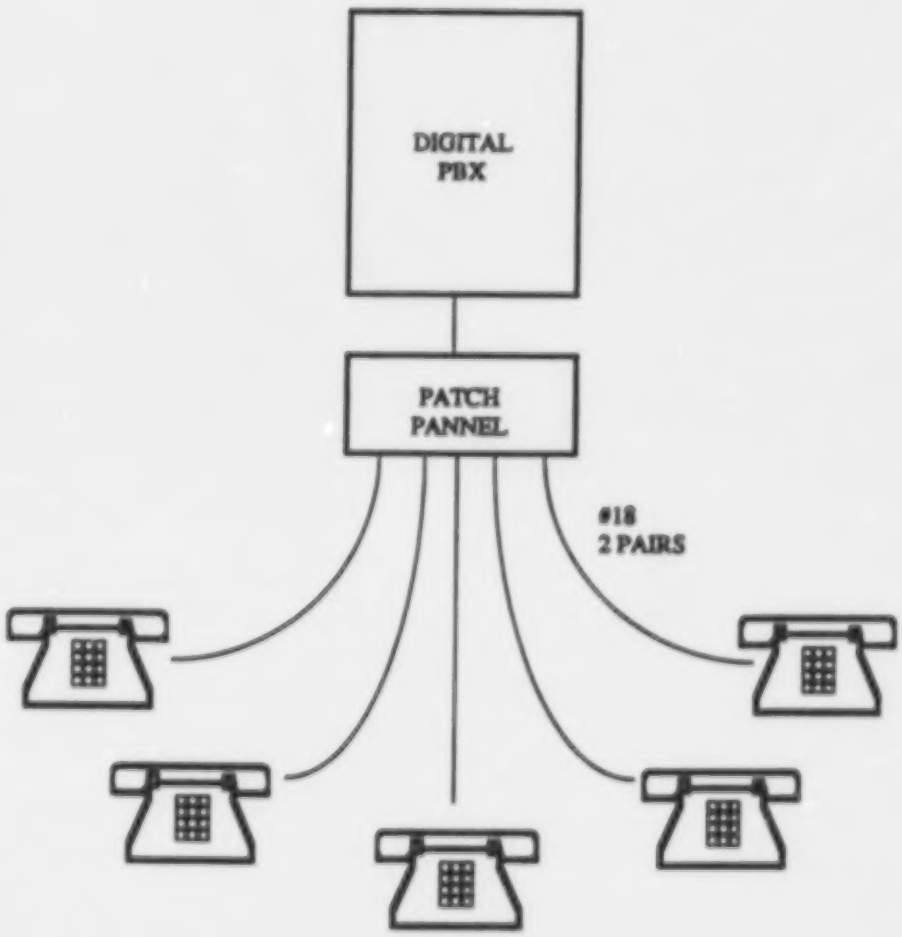
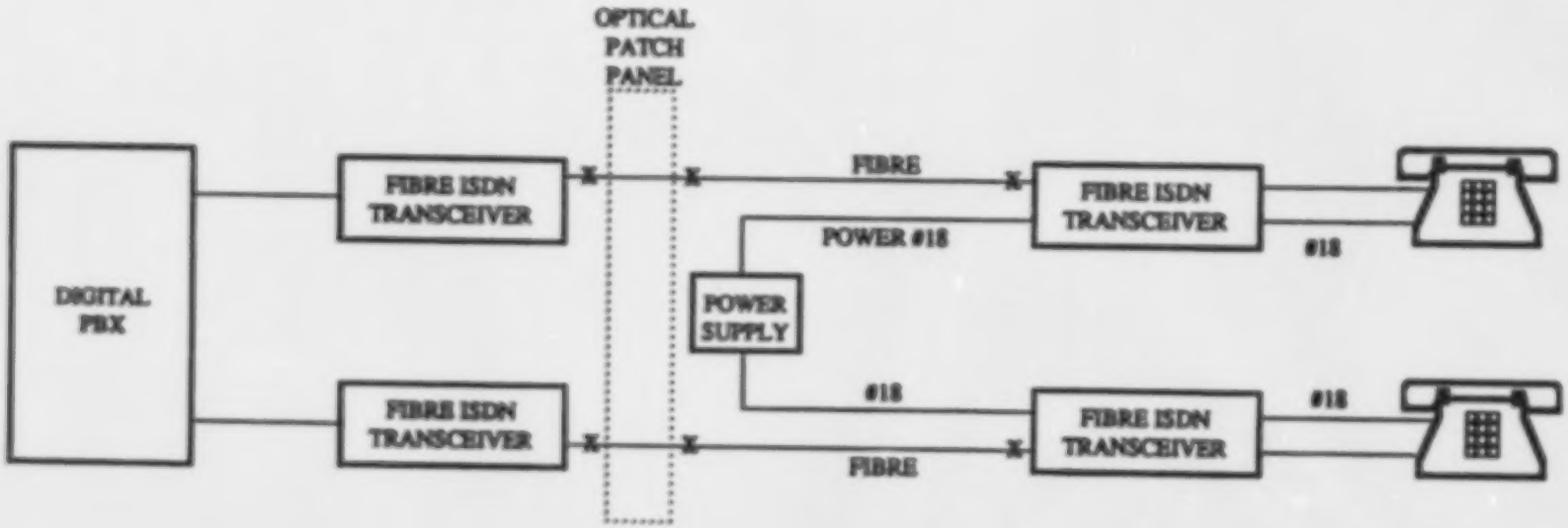


Figure 4. PBX subsystem - Fibre one-to-one replacement



6.3.2.2 Cost Comparison

The incremental costs associated with both systems are presented in Tables 7 and 8 as part of Appendix B.

A total incremental cost of $ 8220 has been estimated for the copper subsystem installation.

The incremental cost of the fibre one-to-one replacement subsystem is estimated at $ 150,500. Most of the cost is associated with the fibre/copper interface units which have to be developed at an estimated average cost of $ 1500 per unit for a total cost of $ 114,000.

The cost of labour related to the installation of bulkhead penetrations and cross connects as well as cable pulling is assumed to be the same for both systems and, therefore, the incremental cost is considered nil.

6.3.2.3 Conclusion

The fibre optic-based implementation should eliminate most of the problems associated with cross-talk and RFI affecting the current analog PBX subsystem.

Little or no gain in cable weight is achieved with the replacement since each telephone interface requires remote power fed via an hybrid cable (two-fibre plus one pair copper).

Since digital telephone systems are well suited to be integrated with a high speed digital stream, the fibre optic-based system can be easily adapted to a high speed LAN, such as an FDDI 100 Mbps backbone network.

6.3.3 *TV Entertainment System*

6.3.3.1 *Technical Comparison*

The existing TV distribution system consists of 7 RG-59 coaxial lines that connect all 48 TV sets on board by means of splitters. Fourteen TV channels are combined and the resulting signal is further mixed with FM and AM radio channels. The AM radio band produces an undesirable modulation of the existing TV signal.

A fibre optic-based system would reduce radio interference and would improve the quality of the received TV signal.

The proposed design of the fibre optic-based system (Figure 5) consists of two fibre cables each one connecting 24 TV sets via optic couplers.

An average loss of 0.5 dB per coupler is estimated, which amounts to 12 dB per cable run, still under the estimated power budget of 15 dB. The multi-channel fibre transmitter and receiver units are commercially available from several suppliers priced at $ 15,000 and $ 10,000 each respectively.

6.3.3.2 *Cost Comparison*

The incremental costs associated with both systems are presented in Tables 9 and 10 as part of Appendix B.

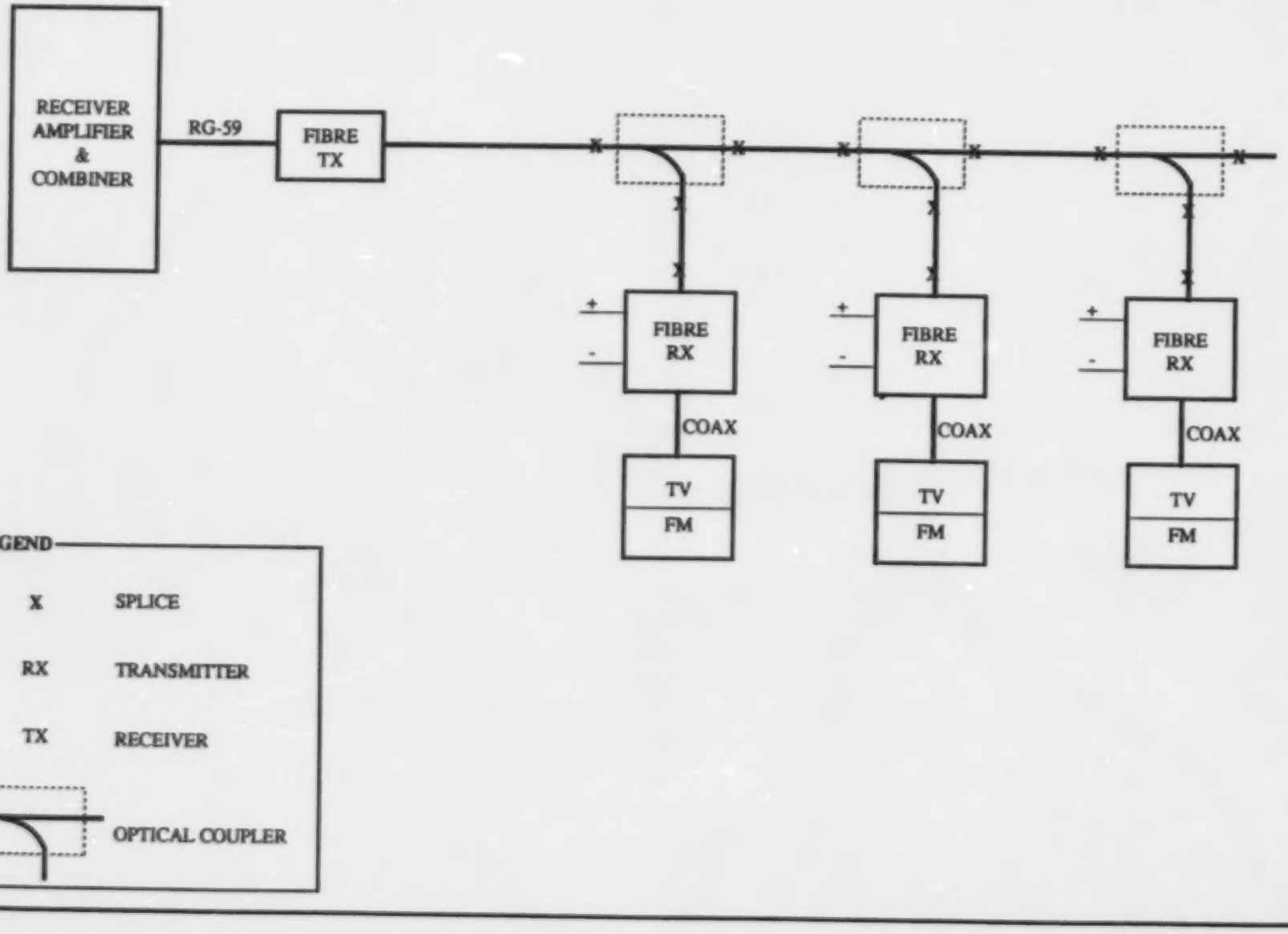
The incremental cost of the coaxial cable installation is estimated at $ 9,480. The incremental cost of the fibre optic-based system is estimated at $ 561,820. This high cost is attributed to the expensive multichannel interface units.

The cost of labour related to the installation of bulkhead penetrations and cross connects as well as cable pulling is assumed to be the same for both systems and, therefore, the incremental cost is considered nil.

6.3.3.3 *Conclusions*

The fibre optic-based TV system is not a candidate for integration; furthermore, its high replacement cost makes it difficult to justify.

Figure 5. TV entertainment system - Fibre one-to-one replacement



6.3.4 Propulsion Control System

6.3.4.1 Technical Comparison

The existing propulsion control system is supplied by General Electric and consists of three SCR-controlled cycloconverters, that feed power to the synchronous motor, driving the propeller shaft.

The existing system has encountered several serious problems related to RFI. One notable such problem is that portable VHF radios operating in the neighbourhood of the SCRs can cause the motor to stop.

Five circuits identified as problematic offer good potential for the use of fibre optics. They are identified in Figure 6 as:

- Speed reference (from telegraph)
- Rotor position feedback
- SCR current feedback (3)

The speed reference and the grey encoded rotor position feedback cable can be replaced with available RS-422 fibre optic interfaces. The current feedback cables require a special design.

Sensors reflecting the status of the propulsion control system are located on the main bridge and in the Engine Control Room. These sensors are considered redundant with those used in the alarm monitoring and control system. As suggested by CCG personnel, some benefit could be obtained if the propulsion monitoring system were to be integrated with the ship's main alarm monitoring and control system. This is reflected in the fibre optic-based design of Figure 7.

Figure 6. Propulsion control system - Copper installation (Port and starboard)

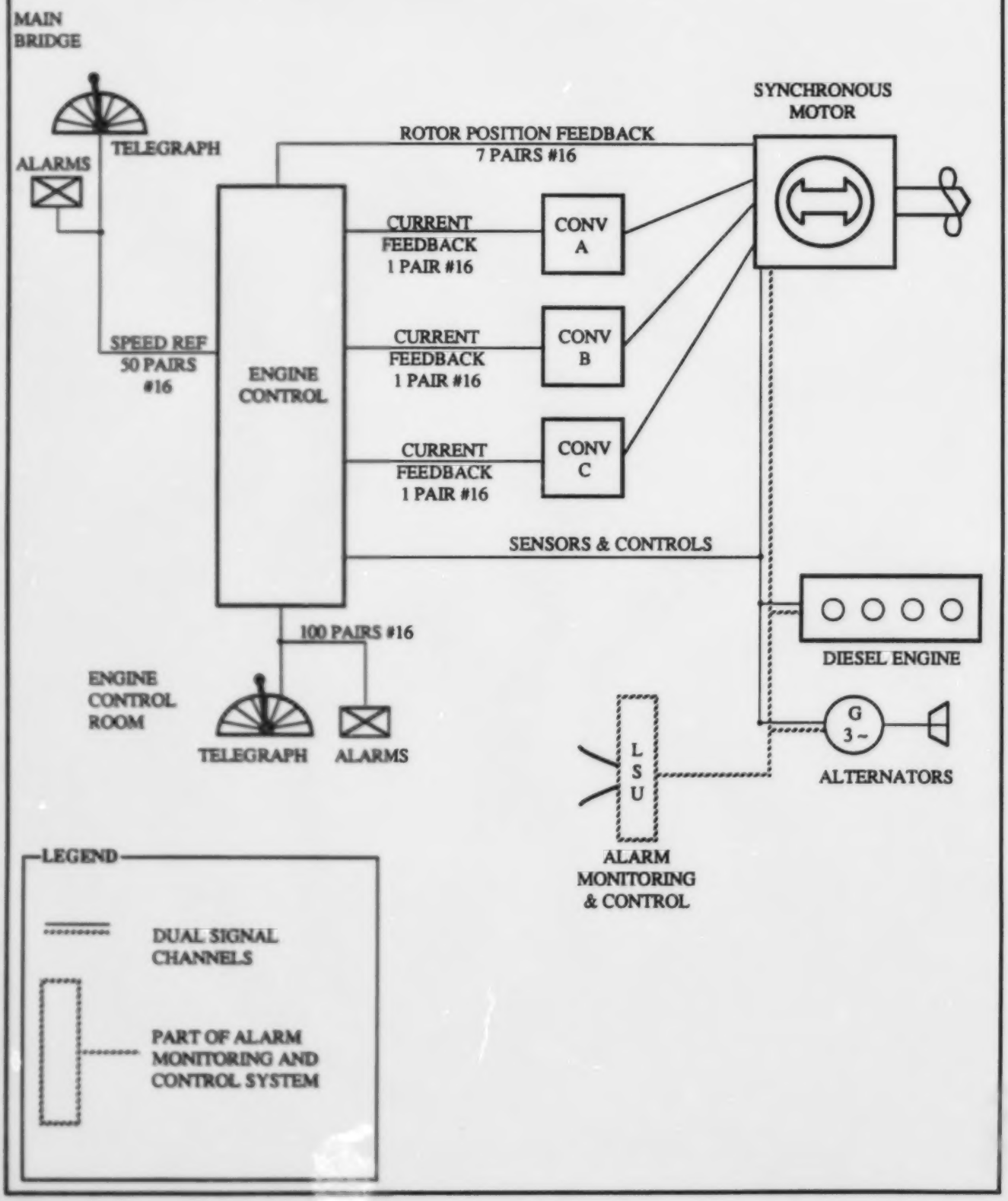
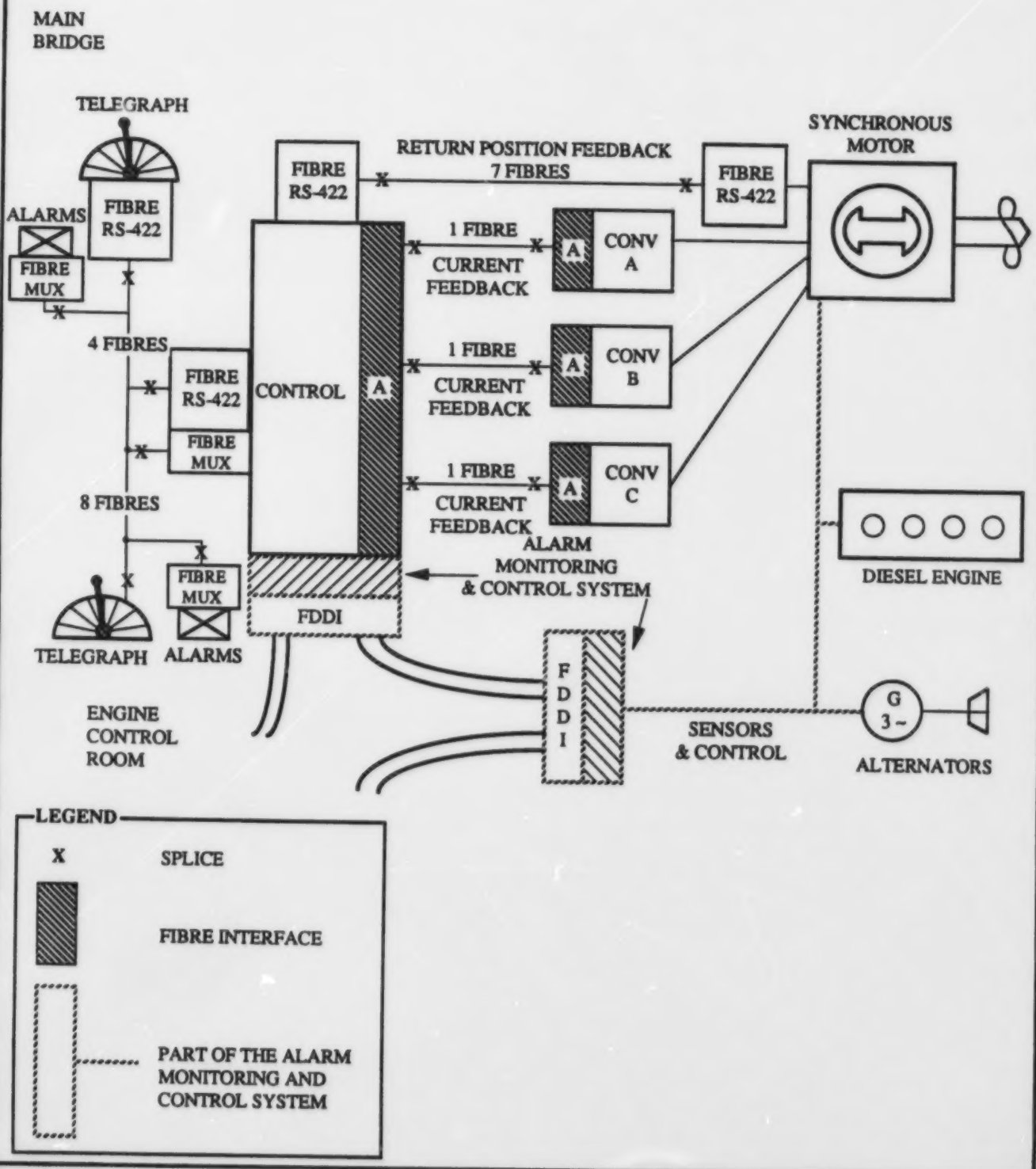


Figure 7. Propulsion control system - Fibre one-to-one replacement



6.3.4.2 *Cost Comparison*

The incremental costs associated with both systems are presented in Tables 11 and 12 as part of Appendix B.

The incremental cost of the copper-based system is estimated at $ 10,500 while the incremental cost of the fibre optic-based system is estimated at $ 17,380.

The cost of labour related to the installation of bulkhead penetrations and cross connects as well as cable pulling is assumed to be the same for both systems and, therefore, the incremental cost is considered nil.

The cost difference is minor considering the importance of the propulsion control system.

If the redundant sensors and controls were eliminated, considerable savings could be achieved. The financial impact of this change has not been considered as part of the study and is not included in the report.

6.3.4.3 *Conclusions*

The fibre optic-based propulsion control system offers a high replacement value. The benefits - RFI elimination and improved safety - outweigh the slightly higher incremental costs of the fibre optic system installation.

Additional benefits can be obtained by eliminating machinery control sensors and alarms that are inherent to both the propulsion control and the alarm monitoring and control systems.

6.3.5 Fire Detection System

6.3.5.1 Technical Comparison

The copper-based fire detection system (Figure 8) consists of a single three-wire loop running through the vessel, to which all sensors are attached. Typical sensors are: smoke detectors, temperature sensors and pull switches.

Sensors are data-addressable and receive power from the central equipment. Problems associated with electric sensors are their sensitivity to EMI and the difficulty of fault isolation.

The fibre optic-based fire detection system (Figure 9) consists of a dual fibre loop, where each sensor receives and transmits signals via two optic couplers. One pair of copper wires is added to the fibre cable in order to provide remote power to the sensors.

A total of 12 fibre loops (24 sensors each) have been allocated to permit a sufficient loss margin per cable run (12 dB on a power budget of 15 dB).

6.3.5.2 Cost Comparison

The incremental costs associated with both systems are presented in Tables 13 and 14 as part of Appendix B.

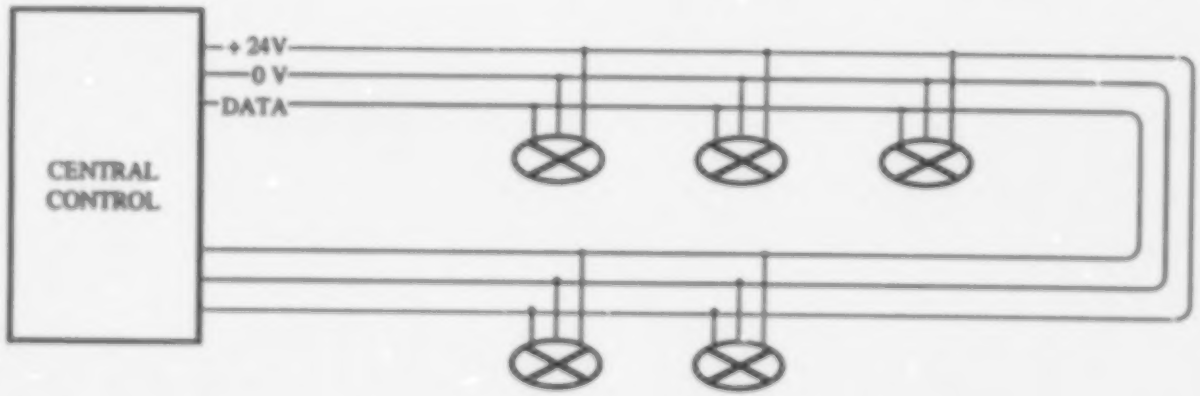
The incremental cost of replacing the copper-based fire detection system is estimated at $ 16,080.

The incremental cost of the fibre optic-based system is estimated at $ 256,760.

The cost of labour related to the installation of bulkhead penetrations and cross connects as well as cable pulling is assumed to be the same for both systems and, therefore, the incremental cost is considered nil.

An interesting aspect of the fibre optic-based system is that all hardware modules are commercially available. The relatively high cost is due to the large number of couplers and connectors required.

Figure 8. Fire detection system - Copper installation

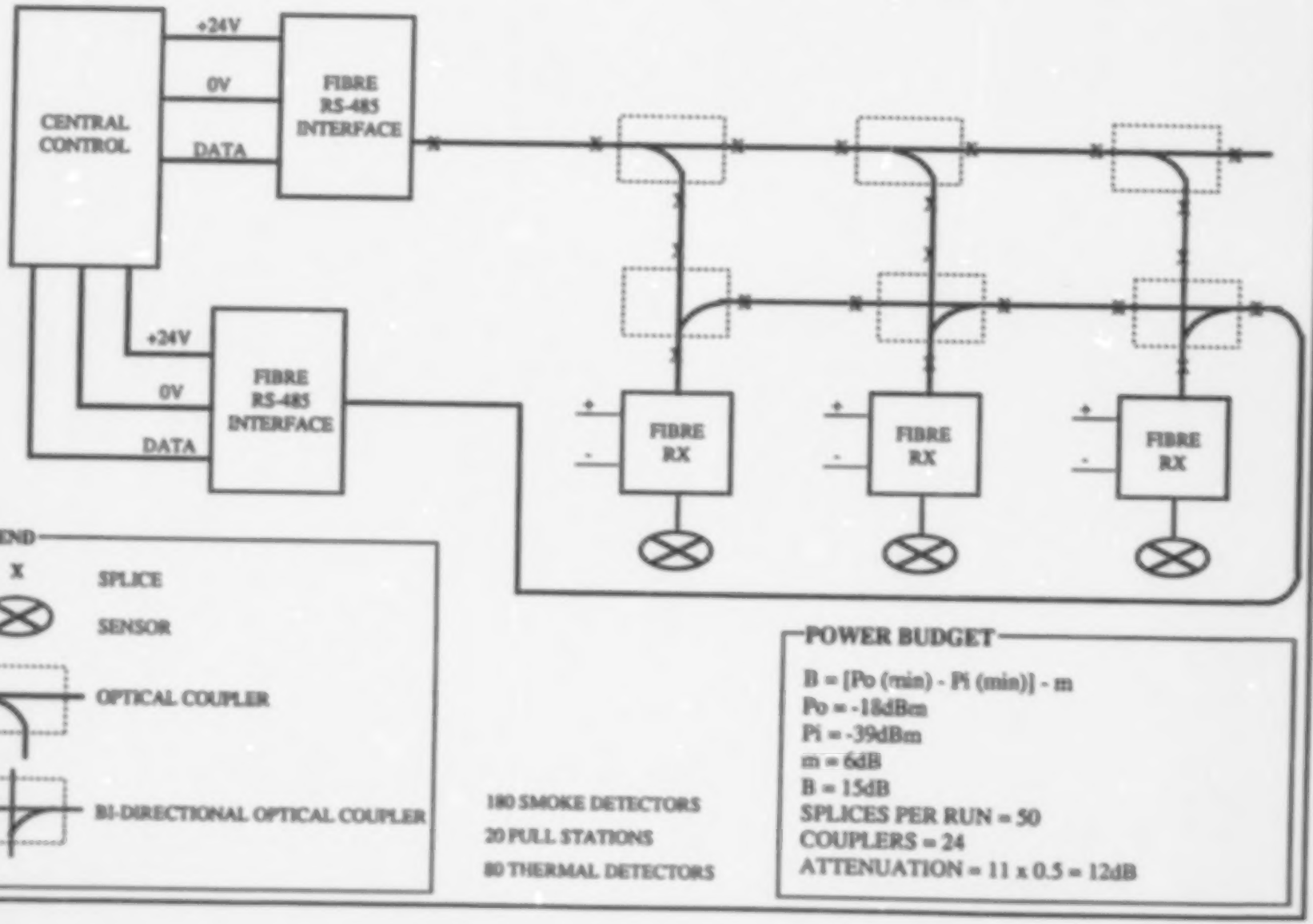


180 SMOKE DETECTORS

20 PULL STATIONS

80 THERMAL DETECTORS

Figure 9. Fire detection system - Fibre one-to-one replacement



6.3.5.3 *Conclusions*

The fibre optic-based system is more expensive than the copper-based system.

There is no reduction in weight achieved with the fibre optic-based system since a hybrid cable is required to provide power to the sensor units.

However, the fibre optic-based system is less sensitive to EMI and to false alarms.

The fibre optic-based system is also better suited for integration with a backbone LAN network since the information transmitted is in digital format and the system covers most areas of the ship.

6.3.6 *Alarm Monitoring & Control System*

6.3.6.1 *Technical Comparison*

The existing copper-based alarm monitoring system, manufactured by Racal-Decca, is based on a backbone ring topology that links 12 Local Scanning Units (LSU). Each LSU permits the concentration of up to 32 sensors in a star configuration (Figure 10). A total of 375 sensors exist on board.

In the case of either a link or LSU failure, the ring topology permits access to the network from either side of the ring. This type of topology resembles a local area network and its implementation with fibre optics is classified as a LAN.

Links to the "Sestron" monitor (fuel consumption) and to the Chief Engineer's Room are RS-232 and RS-422 standard interfaces. Their fibre optic replacement is straight forward since the modems accommodating these interfaces are readily available from several suppliers (Thomas & Betts, Sunher, etc).

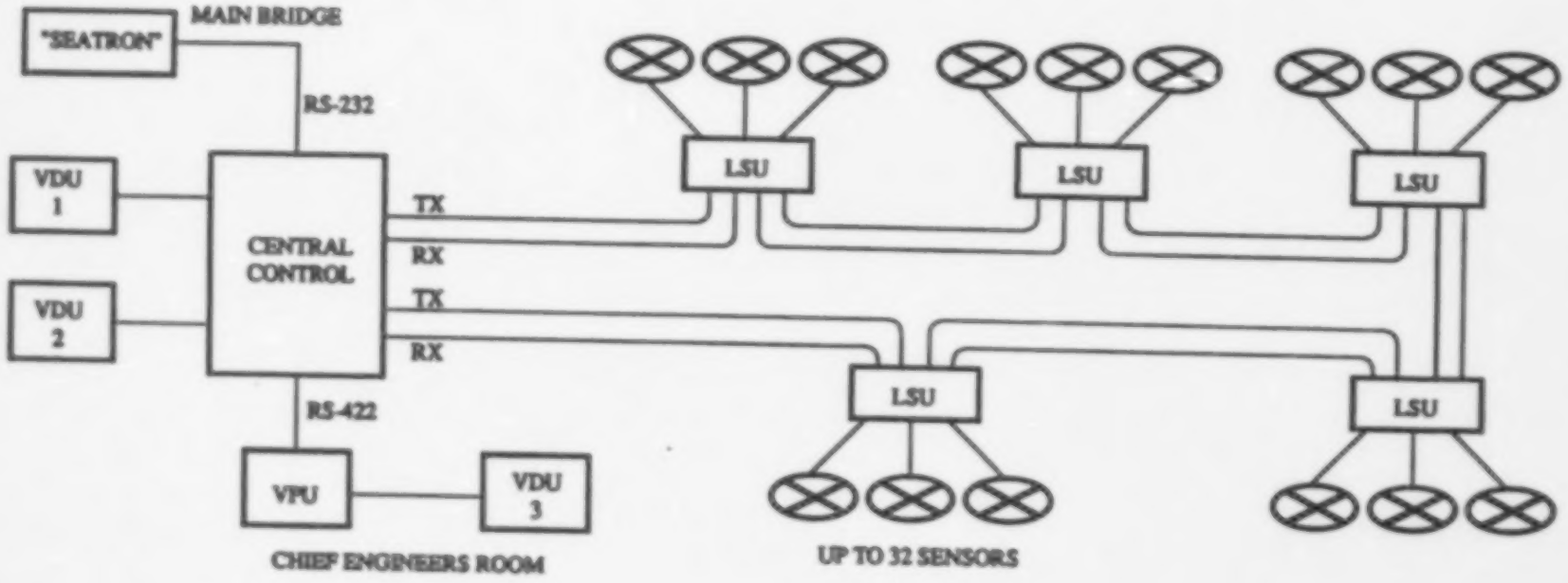
The total estimated length of cable used in the alarm monitoring and control system is approximately 11.5 km with a total estimated weight of 2150 kg.

The advantages of replacing copper-based powered sensors with fibre optic sensors are particularly attractive for combat vessels, where regular sensors tend to produce false alarms under extreme operating conditions. The key advantages of optic sensors are:

- No electrical power required
- Less weight
- Better resistance to high temperatures, explosions and EMI
- Better resistance to nuclear radiation

The replacement of the existing systems backbone network with fibre optic cable is feasible and relatively inexpensive if incorporated within an integrated LAN, as shown in Figure 22. This implementation is analyzed under "Integrated Systems Approach" in Section 6.4.

Figure 10. Alarm monitoring and control system - Copper installation



LEGEND

PRESSURE AND TEMPERATURE SENSORS

LSU — LOCAL SCANNING UNIT

CABLE TYPE:	#14 SHIELDED(BELDEN 8720)
CABLE LENGTH (EST):	11 500m
NUMBER OF SENSORS:	375
NUMBER OF LSU:	12
CABLE WEIGHT:	2150Kg

6.3.6.2 *Cost Comparison*

The incremental cost of replacing the existing copper-based dual ring backbone with a new copper cable is estimated at $ 5880. The incremental costs associated with this system are presented in Table 15 provided in Appendix B. This includes backbone cables and installation costs.

The incremental cost of the fibre optic-based integrated network interface (Figure 20) is estimated at $ 65,040. The incremental costs associated with this system are presented in Table 23 provided in Appendix B. This does not include the corresponding cost portion of the FDDI backbone network.

A more expensive approach is the all fibre option including fibre optic sensors, as shown in Figure 21. In this design, both the sensors and the cables linking them are replaced with fibre optic components. The estimated incremental cost of this design is $ 316,700, as presented in Table 24 provided in Appendix B.

6.3.6.3 *Conclusions*

The alarm monitoring and control system is an excellent candidate for replacement with an integrated fibre optic network as presented in Section 6.4 of this report.

Additional benefits can be obtained by eliminating the redundancy of machinery control sensors and alarms that are inherent to both the alarm monitoring and control and the propulsion control systems.

6.3.7 *Video Surveillance System*

6.3.7.1 *Technical Comparison*

The video surveillance system (Figure 11), for which only one camera and one TV set have been used in the analysis, consists of one coaxial RG-59 cable and a two-pair cable to carry power and data required to feed the camera and the attached servomotor.

Depending on the location of the camera, EMI may have a serious effect on picture quality. A fibre optic cable could be beneficial in a high noise environment, such as the engine room, for instance, which is exposed to a high level of EMI.

The fibre optic-based cable (Figure 12) consists of two fibres plus one copper pair for power. Both the video (one analog channel) and the data interfaces are readily available at relatively low prices.

6.3.7.2 *Cost Comparison*

The incremental costs associated with both systems are presented in Tables 16 and 17 as part of Appendix B.

The incremental cost of replacing the copper based Video Surveillance System is estimated at $ 420. The incremental cost of the fibre optic-based system is estimated at $ 4680.

The cost of labour related to the installation of bulkhead penetrations and cross connects as well as cable pulling is assumed to be the same for both systems and, therefore, the incremental cost is considered nil.

6.3.7.3 *Conclusions*

The fibre optic-based system is slightly more expensive than the copper-based system. However the advantages of fibre optics, less weight and immunity to EMI, may outweigh the costs involved and make this application a good candidate for replacement.

Figure 11. Video surveillance system - Copper installation

COPPER SYSTEM

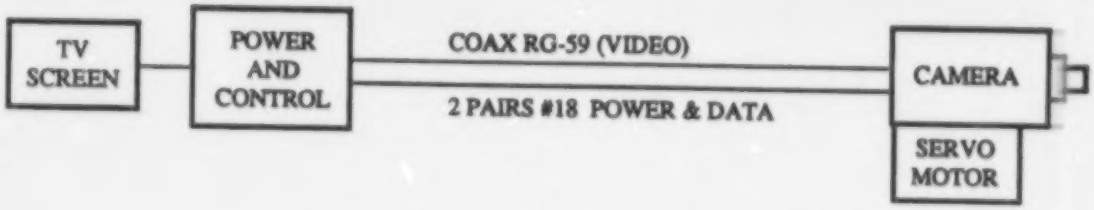
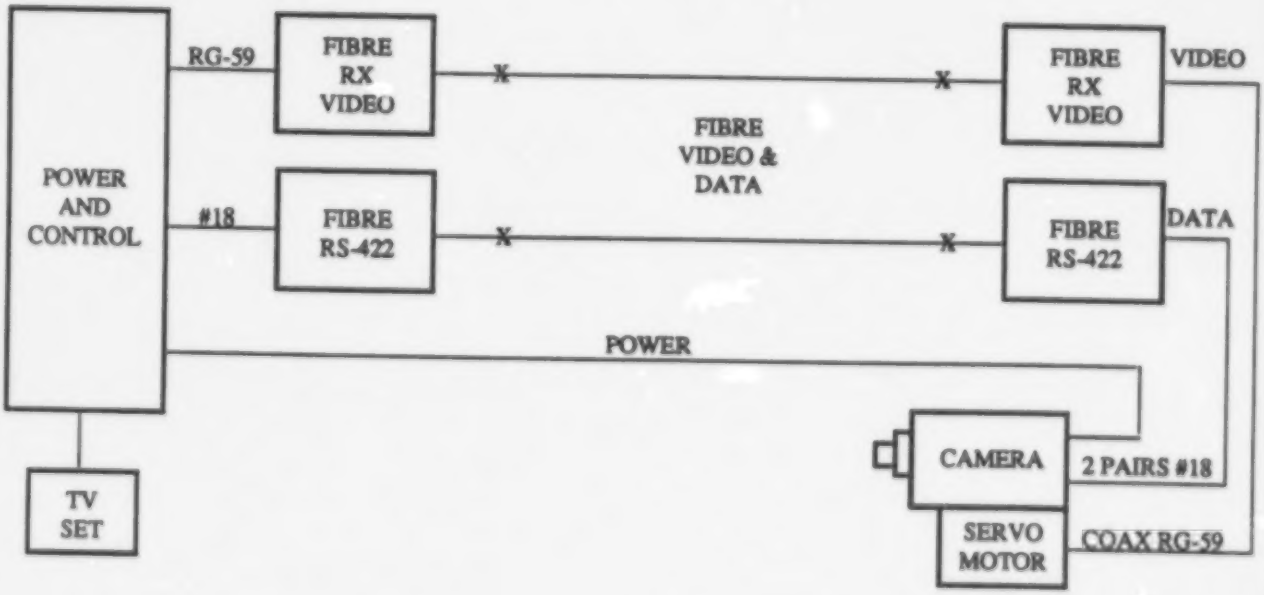


Figure 12. Video surveillance system - Fibre one-to-one replacement



TOTAL FIBRE LENGTH: 100m
TOTAL FIBRE WEIGHT: 4Kg

6.3.8 Gyrocompass System

6.3.8.1 Technical Comparison

The copper installation of the gyrocompass system (Figure 13) consists of 14 cables of four pairs each. Each cable carries five data and two power wires # 14.

The gyro repeaters installed at the main bridge and at the wheelhouse top are driven by servomotors that receive power from the central equipment.

No EMI problem related to the gyro system has been reported to date. However it is well known that magnetic gyro systems may produce errors in high RFI on EMI noise environments.

Electro-optic gyros with better accuracy than the electro magnetic ones, have recently been developed (Sanarch effect).

The proposed fibre optic-based replacement subsystem (Figure 14), uses a hybrid cable to carry both power and data signals.

6.3.8.2 Cost Comparison

The incremental costs associated with both systems are presented in Tables 18 and 19 as part of Appendix B.

The incremental cost of replacing the copper-based gyro is estimated at $ 2580 while the incremental cost of the fibre optic-based system is estimated at $ 67,380.

The cost of labour related to the installation of bulkhead penetrations and cross connects as well as cable pulling is assumed to be the same for both systems and, therefore, the incremental cost is considered nil.

6.3.8.3 Conclusions

The fibre optic system is more expensive than the copper system. The advantages drawn by the fibre optic cable are not as substantial as if the complete gyro system were replaced by an optical gyro. The fibre-based gyro system appears more adequate as an autonomous configuration rather than as part of an integrated network.

Figure 13. Gyrocompass system - Copper installation

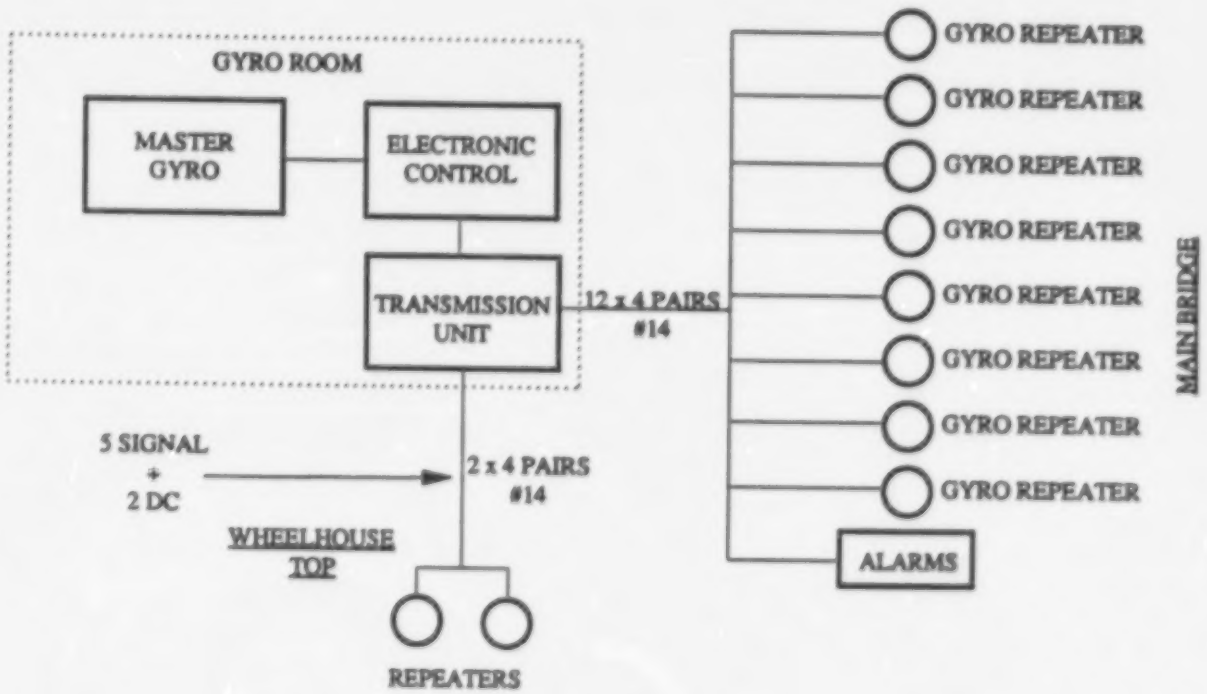
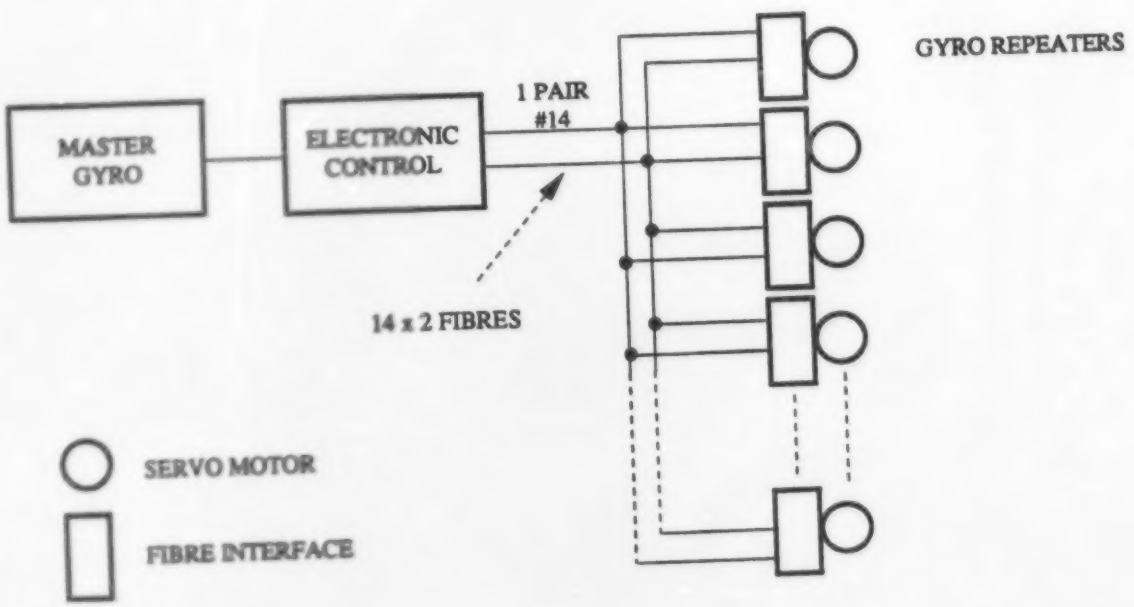


Figure 14. Gyrocompass system - Fibre one-to-one replacement



6.4 INTEGRATED SYSTEM APPROACH

6.4.1 Introduction

From the analysis of the systems evaluated in Section 6.3, we can conclude that certain systems are better suited for an autonomous implementation, while others are excellent candidates for being integrated within a fibre optic LAN throughout the ship.

The characteristics that make a system suitable for integration are:

- Digital data transfer
- Loop topology
- System distributed throughout the ship

The systems best suited for autonomous implementation are:

- TV entertainment system
- Propulsion control system*
- Gyrocompass system
- Video surveillance system

The systems best suited for integration within a LAN are:

- Public addressing subsystem
- PBX subsystem
- Fire detection system
- Alarm monitoring and control system

A description of a fibre optic integrated system using a LAN backbone network and the four integrated systems follows.

---

* Many of the alarms and indicators used in the propulsion control system can be integrated with the alarm monitoring and control system.

6.4.2 *The Backbone Network*

6.4.2.1 *Introduction*

The U.S. Navy has selected a standard fibre optic LAN for shipboard systems integration called SAFENET II (see Chapter 5). This LAN based on the IEEE 802.8 FDDI standard, uses 62.5/125 microns multimode fibre at 100 Mbps and a token ring as the medium access control method.

SAFENET II nodes are being built and sold today by Martin Marietta, Mariland. The components of SAFENET II must meet military specifications and are twice as expensive as FDDI components.

Canadian Coast Guard vessels are subject to extreme weather conditions, but electronics components on board CCG ships do not have to comply to military specifications. Therefore, for a loop LAN configuration, FDDI rather than SAFENET II components will be considered.

6.4.2.2 *Ethernet versus FDDI*

The Ethernet standard is well known in the telecommunications industry. It consists of a bus made of a coaxial cable that permits data transmission rates at 10 Mbps. On board LANs based on Ethernet have been developed by SIEMENS and by Unisys (SHINPADS).

These architectures require multiple redundant buses to compensate for the poor reliability of a single Ethernet bus.

A more modern standard, FDDI (Fibre Distributed Data Interchange) is being developed. A dual fibre ring and nodes with inherent automatic reconfiguration software permit instant recovery in case of a single loop or node failure.

The U.S. Navy has chosen FDDI for its simplicity of operation and higher survivability than Ethernet. Upgraded to Navy requirements, the FDDI based standard LAN is called SAFENET II.

The advantages of FDDI networks versus Ethernet are as follows:

- FDDI is suited to fibre optics implementation (dual ring) while Ethernet is not (broadcast bi-directional bus). Ethernet's fibre implementation requires special bi-directional couplers that are more expensive and delicate to adjust than the standard point-to-point FDDI interfaces.

- The FDDI protocol (token ring) is known to be response time predictable and more suited to high traffic density than Ethernet.

- Voice integration is feasible with FDDI at 100 Mbps (24 voice channels represent 1.5 Mbps or 1.5% of the total capacity).

  With Ethernet, a 24 channel voice network represents 15% of the total capacity. Since contention (collisions) often occurs at high utilization rates (above 30%) and priority schemes are not possible, voice integration is not seriously considered by suppliers of Ethernet.

  FDDI's bandwidth capacity is better suited for the integration of existing subsystems to the network and for the development and integration of future applications.

- Finally FDDI's inherent reliability is higher than Ethernet's.

For all these reasons, the proposed shipboard LAN design is based on the FDDI architecture.

6.4.2.3 *Basic FDDI Network*

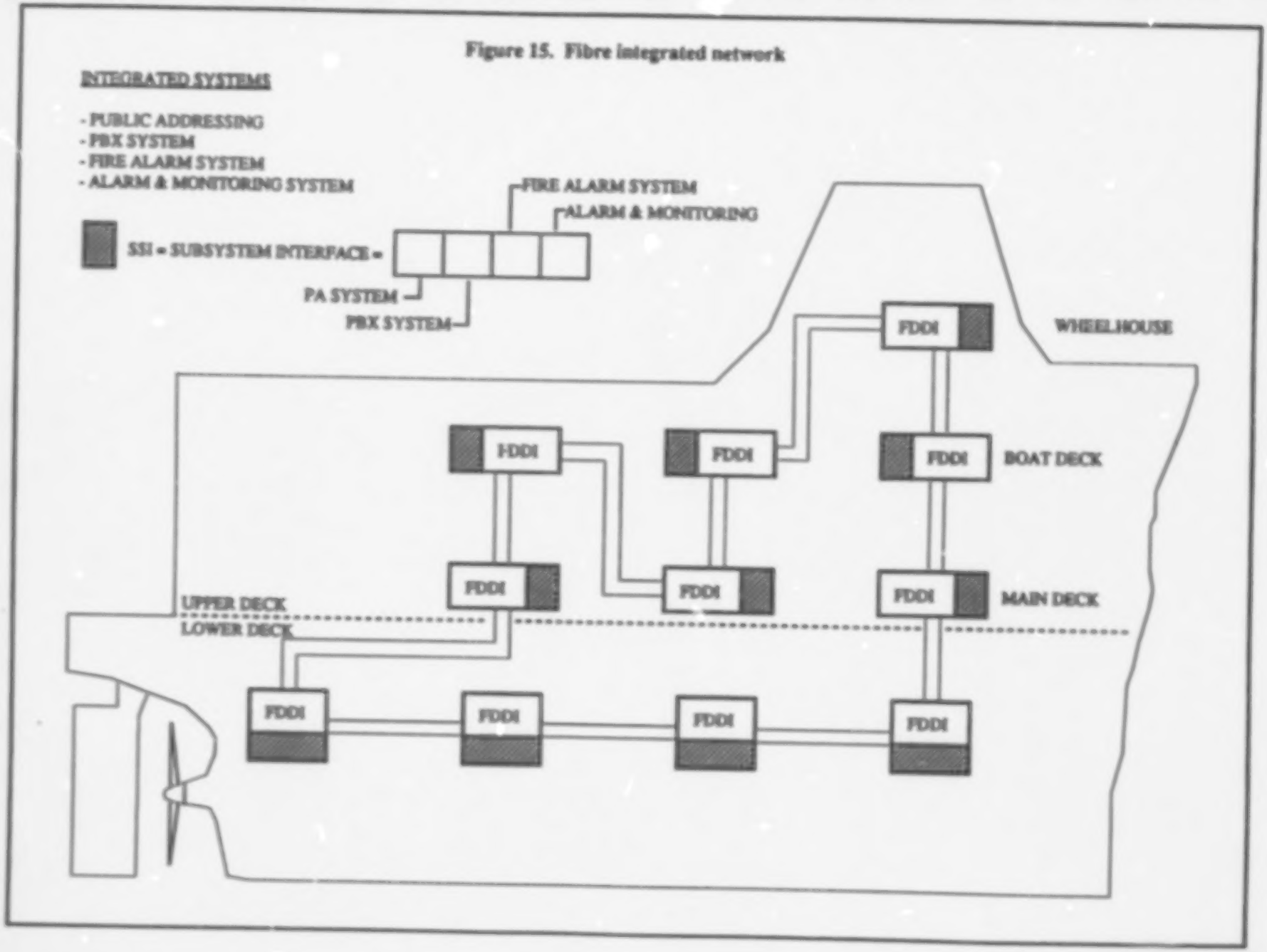
The existing Alarm Monitoring & Control system nodes are used as the basis for the topology of the FDDI LAN.

Twelve nodes scattered throughout the ship accommodate the different interfaces required by the four systems considered suitable for integration.

The integrated LAN permits a reduction of cable length and weight since all peripheral units are linked to the nearest FDDI node, thus eliminating cabling redundancies.
Another advantage of this approach is that the FDDI interface bus, where peripheral units are linked becomes a standard for all suppliers improving maintenance procedures and providing CCG with a better selection of suppliers.

A general configuration of the LAN topology is presented in Figure 15.

Figure 15. Fibre integrated network



6.4.3 *Public Addressing Subsystem Integrated Approach*

Two different types of FDDI interfaces have to be developed for this subsystem: one audio transmitter for the receiving speakers and one audio transceiver for the talk-back speakers. The latter devices are connected in a star configuration while the former devices are connected on a bus configuration (Figure 16).

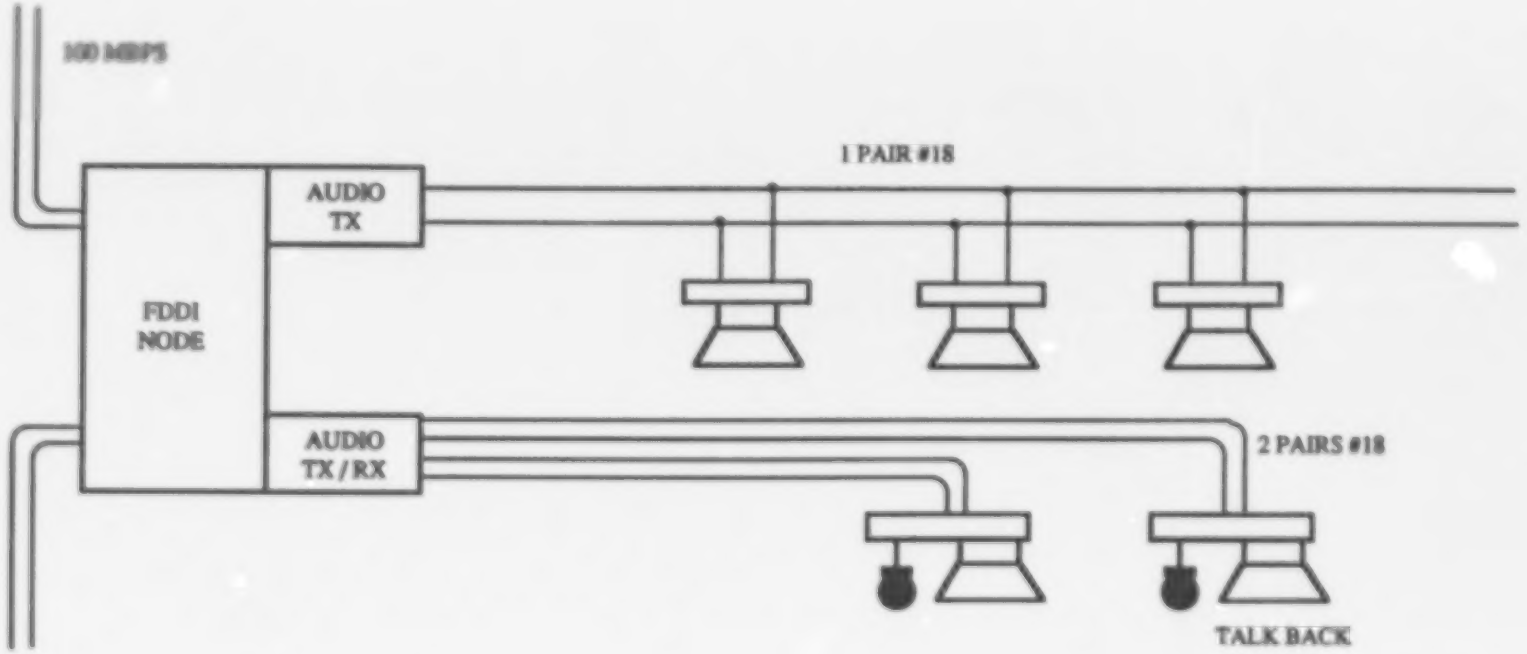
The incremental cost of this subsystem is estimated at $ 86,480 excluding the proportional cost of the backbone network. The incremental costs are presented in Table 20A as part of Appendix B.

The advantages offered by this approach versus the one-to-one replacement approach are:

- Shorter runs of cable resulting in better utilization of the ships conduits
- Reduction in cable weight
- Use of existing speaker housing
- Lower costs

The fibre optic-based LAN backbone network is a prerequisite for the integration of the application.

Figure 16. Public addressing subsystem - Fibre integrated network



6.4.4 PBX Subsystem Integrated Approach

Under this approach, telephones are connected to the nearest FDDI node via a standard two-pair # 18 copper cable. It is assumed that the telephone loops are digital, PCM coded (1 voice channel = 64 Kbps).

The FDDI node has a digital voice interface that permits a constant capacity allocation of 1.544 Mbps (24 voice channels) in the backbone data stream of 100 Mbps (Figure 17).

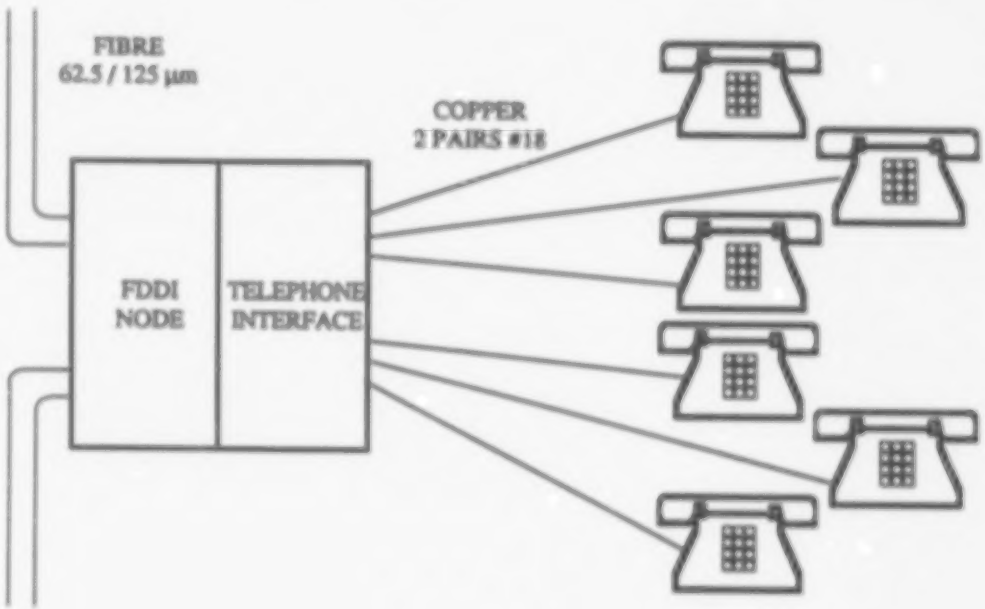
The incremental cost of this subsystem is estimated at $ 33,000 excluding the proportional cost of the backbone network.

The incremental costs are presented in Table 20B as part of Appendix B.

The advantages offered by this approach versus the one-to-one replacement approach are the same as the ones identified for the PA system.

The fibre optic-based LAN backbone network is a prerequisite for the integration of this application.

Figure 17. PBX subsystem - Fibre integrated network



6.4.5 Fire Detection System Integrated Approach

6.4.5.1 Hybrid Design

The fire detection system uses a digital loop configuration and it is well suited for integration with the ship's backbone LAN.

Under the integrated approach, 12 copper loops are used, one per FDDI node. This way, the total length of cable is substantially reduced and the basic reliability of the system is improved (Figure 18).

The incremental cost of this system is estimated at $ 64,200 excluding the proportional cost of the backbone network.

The incremental costs are presented in Table 21 as part of Appendix B.

The relatively lower cost is due to the hybrid design based on the original sensors, protocol and cable of the existing system while a new interface, to be developed, has been added at each FDDI node.

6.4.5.2 All-fibre Design

An all-fibre design for the fire detection system (Figure 19) implies the replacement of all sensors and cables with fibre optic components.

Fibre optic sensors, more immune to EMI and less error prone than the electrical ones, have been developed by several companies over the last few years.

The incremental cost of this subsystem is estimated at $ 195,600 excluding the proportional cost of the backbone network.

The incremental costs are presented in Table 22 as part of Appendix B.

Figure 18. Fire detection system - Fibre integrated network (Existing sensors)

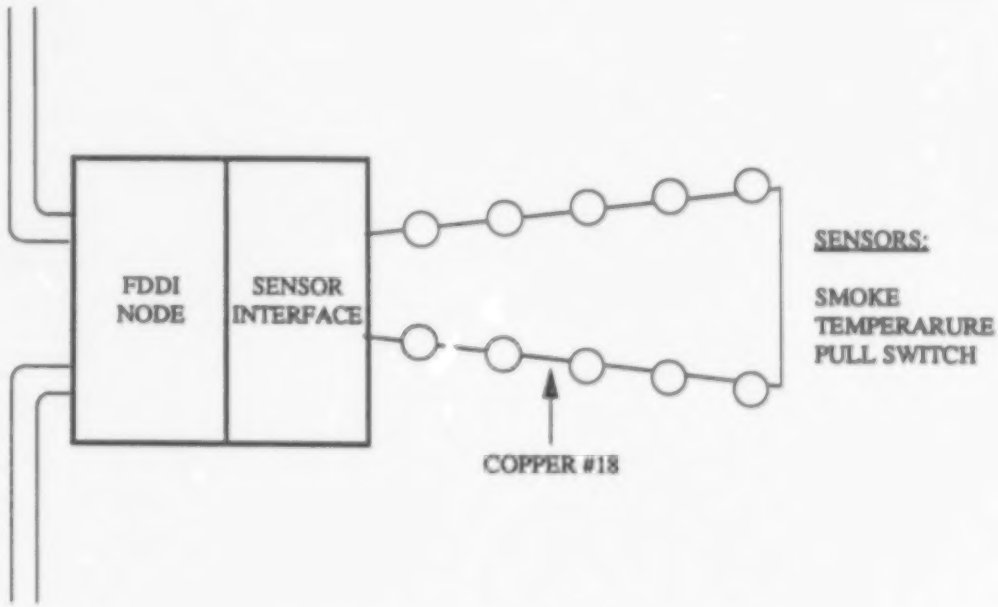
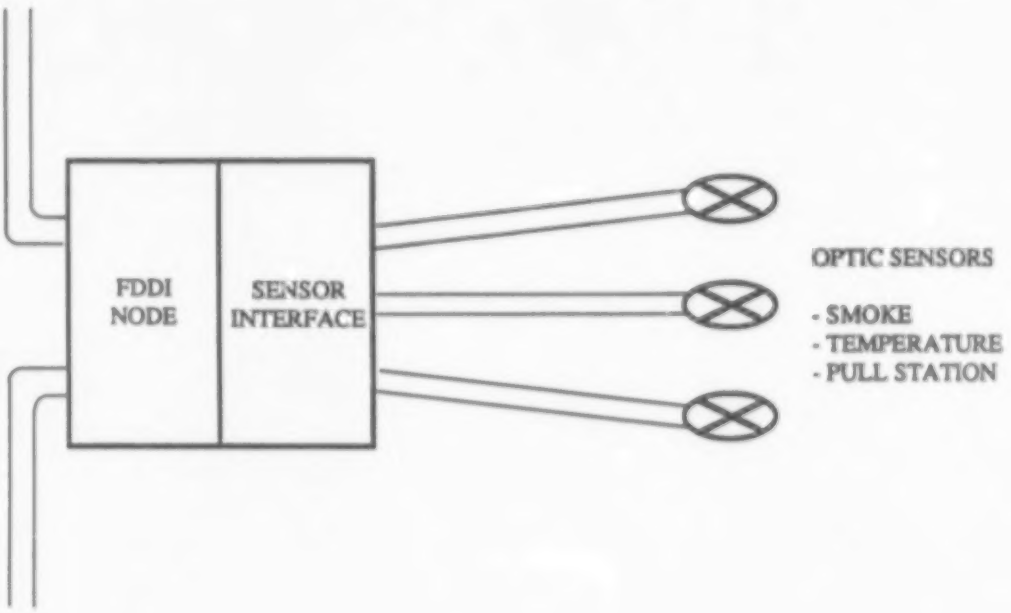


Figure 19. Fire detection system - Fibre integrated ship control (Optic sensors)



6.4.6 Alarm Monitoring & Control System Integrated Approach

6.4.6.1 Hybrid Design

The existing alarm monitoring and control system is based on a loop configuration and, therefore, is well suited for integration within an FDDI LAN.

Under the hybrid design (Figure 20) the existing LSUs, sensors and cables are kept. Only the LSU-FDDI interface has to be developed at an estimated average unit cost of $ 4000.

The incremental cost of the integrated hybrid approach (FDDI backbone plus copper distribution network) is estimated at $ 65,040 excluding the proportional cost of the backbone network.

The incremental costs are presented in Table 23 as part of Appendix B.

For more details, refer to section 6.3.6.

6.4.6.2 All-fibre Design

Under this design (Figure 21), optic sensors are used; only one transmitting fibre and one receiving fibre for the optical signal are required. The sensor operates without electrical power and consideration should be given to the optical loss introduced by the sensor.

Optic sensors for shipboard use are of great interest to the U.S. Navy and are manufactured by several companies on a demand basis.

The incremental cost of the all-fibre design is estimated at $ 316,700.

The incremental costs are presented in Table 24 as part of Appendix B.

Figure 20. Alarm monitoring & control system - Fibre integrated network (Existing sensors)

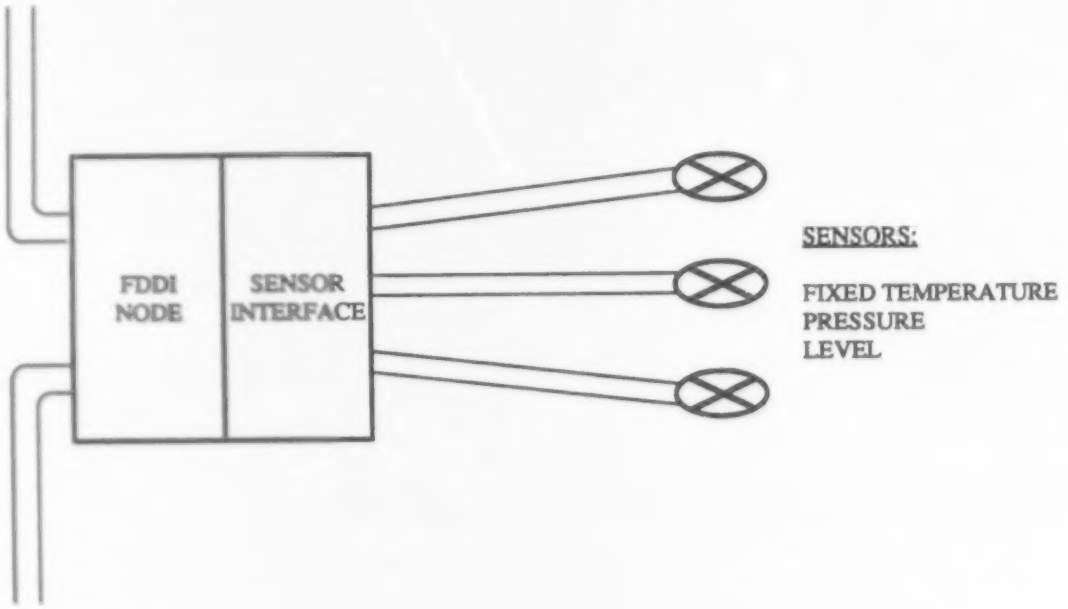


Figure 21. Alarm monitoring & control system - Fibre integrated network (Optic sensors)

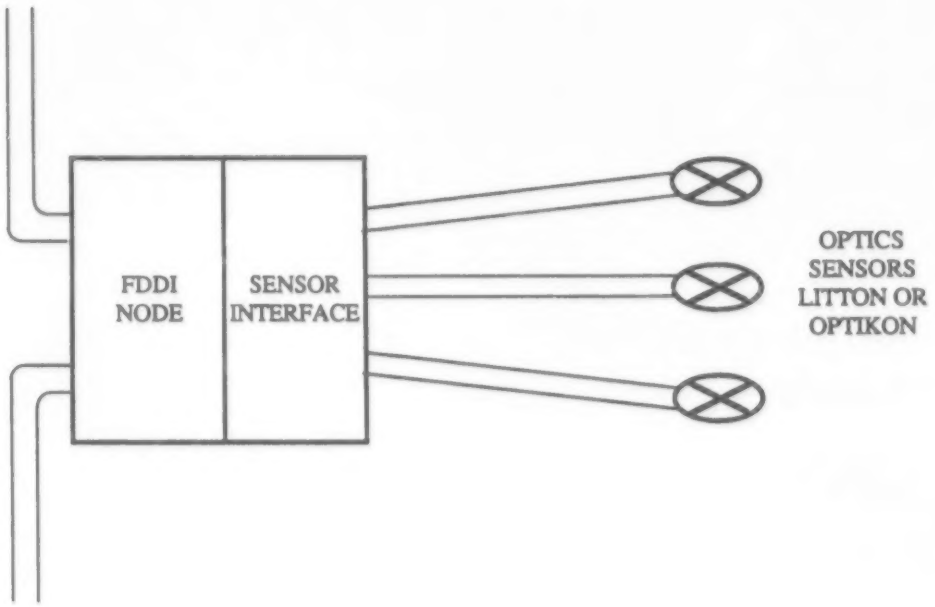
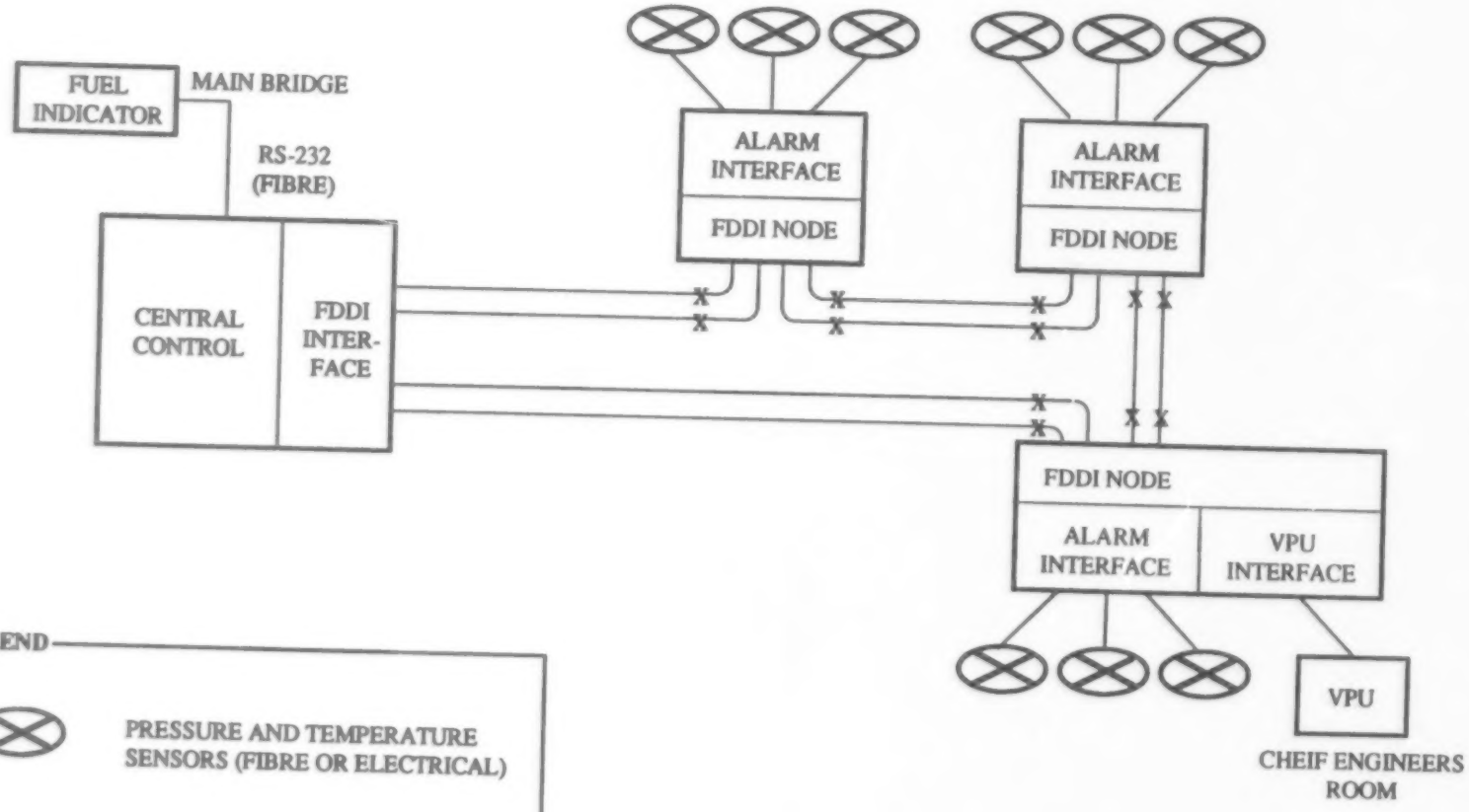


Figure 22. Alarm monitoring & control system - Fibre integrated replacement



6.4.7 *Cost Comparison*

A summary of the incremental costs for the four systems considered as part of a fibre optic integrated network is presented in Table 25 as part of Appendix B.

The total incremental cost of replacing these systems under the one-to-one replacement approach is $ 912,080* compared to $ 474,120 (Table 25) for the integrated approach or a ratio of 2 to 1.

The one-to-one replacement approach provides end-to-end fibre connectivity, while the integrated approach initially reduces fibre connectivity to the backbone network.

The peripheral links remain copper-based. The integrated hybrid topology is more cost-effective and flexible than the all-fibre configuration. It can be built in phases based on particular requirements, first the backbone, then the development of individual system interfaces, each using the common FDDI standard.

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* This total was obtained by adding the following sub-totals:

- PA (Table 6)	$ 214,500
- PBX (Table 8)	152,300
- FDS (Table 14)	254,840
- AMS (Table 25)	65,040
- Backbone (Table 25)	225,400
	$ 912,080

6.5 MAINTENANCE COSTS

The installation of a fibre optic-based system, as described in the present report, represents in all cases an increase in the direct maintenance costs usually associated with the more complicated interface unit of such systems.

This results from the design approach taken in the study. We are not replacing the control and peripheral units but rather encapsulating them with new interfaces that naturally add to the complexity of the overall system, thus increasing maintenance costs.

We have estimated maintenance costs according to the following guidelines:

Component	Maintenance Cost
Fibre cable	$ 0/year
Copper cable	$ 0/year
Couplers, splices	$ 0/year
Interface units	5% of purchase cost per year

Discussions with CCG personnel have confirmed that cabling rarely requires any repairs. Most of the maintenance activities are performed on terminal equipment units.

Fibre optic components are fairly reliable with the drivers offering the lowest MTBF (average 23 years). Accordingly we apply a maintenance cost of 5% of purchase value per year.

6.6 SYNOPSIS

A summary of the results of the study is presented in Table 26.

Table 26 . Synopsis results

SYNOPSIS	Incremental costs		Fibre optic perspective	Potential for integration	Autonomous systems	Power requirements	Weight reduction	Bandwidth improvement	Immunity to EMI	Safety improvement
A. INDIVIDUAL SYSTEMS	Copper	Fibre optic	Short term 1-3 years							
1. Internal communication system										
A. PBX Subsystem	10 980	151 300	NO	YES	-	REMOTE	NO	YES	YES	-
B. Public addressing subsystem	20 760	214 550	NO	YES	-	REMOTE	NO	YES	YES	-
2. TV entertainment distribution system	11 520	564 220	NO	NO	YES	LOCAL	YES	YES	YES	-
3. Propulsion control system	13 860	15 880	YES	YES	NO	LOCAL	YES	YES	YES	YES
4. Fire detection system	18 480	254 840	NO	YES	-	REMOTE	NO	YES	YES	YES
5. Alarm monitoring & control system (1)	4 080	65 040(1)	NO	YES	-	REMOTE	NO	YES	YES	YES
6. Video surveillance system	660	5 160	YES	NO	YES	REMOTE	NO	YES	YES	YES
7. Gyro compass system	3 420	67 920	NO	NO	YES	REMOTE	NO	YES	YES	-
B. INTEGRATED SYSTEM			3-5 years	-	-	-		100:1	YES	YES
8. LAN backbone		225 400				LOCAL	-			
A. PBX system		33 000				REMOTE	YES			
B. Public addressing system		86 480				REMOTE	YES			
C1. Fire detection system w/o optical sensors		64 200	-			REMOTE	YES			
C2. Fire detection system with optical sensors		195 600				NO POWER REQUIRED	YES			
D1. Alarm monitoring & control system w/o optics sensors		65 040	-			REMOTE	NO			
D2. Alarm monitoring & control system with optics sensors		316 700				NO POWER REQUIRED	YES			

NOTE (1): LAN BACKBONE REQUIRED

7. FINANCIAL AND ECONOMIC CONSIDERATIONS

7.1 INTRODUCTION

In this chapter, we will discuss the various economic and financial factors affecting the replacement of an existing technology - copper cabling - by a promising new one - fibre optics - for CCG shipboard applications.

We will also discuss briefly the results of the comparative analysis of the previous section and present them in a more global context.

Finally, the content of this chapter represents a slight variation from the net present value and the internal rate of return analyses that we intended to carry out at the outset of the study. As shown in figure 23, the cost curves of the fibre-based and copper systems converge at well over 20 years, which exceeds the period considered for the study.

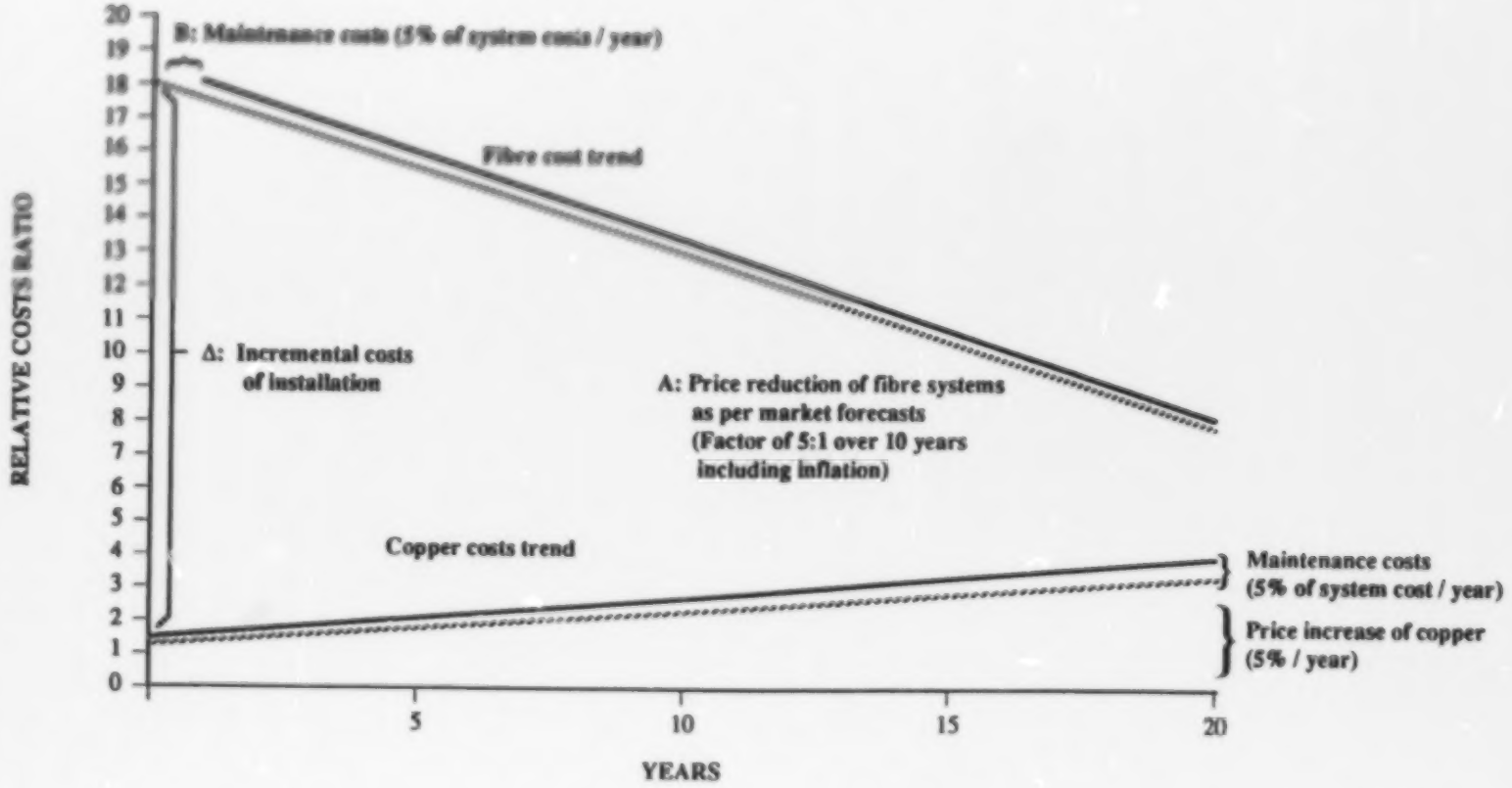
7.2 FINANCIAL CONSIDERATIONS

The comparative technical analysis shows that the existing cabling for the systems considered can be replaced in all cases by an equivalent fibre optic - based configuration. We have indicated how this could be done, at what incremental costs and for what benefits.

The results show that in all cases the fibre optic configuration, based on the assumptions made and the cost information obtained from manufacturers and suppliers for 1989 prices, is more expensive than the equivalent copper cabling equivalent. The difference was an average ratio of 14 to 1 for most systems (1.65 to 26.1), with the exception of the TV Entertainment system with a 59:1 ratio.

This average ratio indicates that it is not cost effective today to consider replacing the existing cabling on board CCG vessels with fibre optics for the proposed systems.

Figure 23 . Costs trends of fibre optic vs copper systems



However, for two of the eight systems, the cost difference is small, $ 6,880 for the propulsion control system and $ 4,260 for the video surveillance system. This can be considered minimal compared to the benefits involved, particularly for the propulsion control system. Therefore, on that basis, the fibre optic-based solution could be envisaged for these two systems.

The fibre optic-based solution would not be appropriate at this point in time for the other systems.

Ideally, the cost results should have been considered in relation to the overall costs of each system under study to determine the ratio of the costs of fibre optic-based cabling to the costs of the overall system. A more realistic cost comparison ratio of fibre optic cost to copper cabling would have emerged.

A relevant case study is Hydro-Quebec, which introduced fibre optic cabling in some of its power plants years ago for safety measures, to protect its personnel against sudden electrical discharges experienced with the conventional shielded cabling. The cost of using fibre optic in this case was 20 to 25% higher than the overall system cost with the conventional cabling, or a ratio of 1:25 to 1 for the overall system ratio. This was justified in the accrued safety benefits, i.e., protection of the life of the operations personnel.

The principal reason for the significant higher costs of the fibre optic-based shipboard systems can be attributed to the requirement to design custom-made interfaces particular to each system. The cost of the cabling itself is not a major factor ($ 3/m for # 18 (Belden) two-pair cable compared to $ 8/m to $ 11/m for fibre optic cabling), considering the possibility of using less cabling with fibre optics and the potential saving in weight.

The U.S. Navy with its SAFENET program is concerned with the higher cost associated with the design of fibre optic-based systems for military use only and would like to be able to benefit from the development of commercially available products and systems. The same reasoning is applicable in the case of the CCG.

The cost of a fibre optic-based system is very dependent on the pricing of particular elements of that system, especially the fibre optic interfaces. The prices are subject to the demand or interest generated for these products in the marketplace and the capacity of companies to supply them at reasonable and profitable prices. The more standardized a product becomes, usually as a result of an industry need, the higher the probability that the prices will decrease over time.

Therefore, based on a cost comparison of 1989 prices, the replacement of the existing cabling on board CCG vessels by a fibre optic alternative, is not a cost effective proposition in the short term, except for the propulsion control system and the video surveillance system, as indicated the previous chapter.

Until prices are reduced considerably other factors, such as solving the RF interference that is affecting the performance of the proposition control system on the Sir Wilfrid Laurier, will have to come into play before the fibre optic technology can be considered appropriate for shipboard applications.

The mid-to-long term scenarios are a different issue and will depend largely on future developments in the field of fibre optics and on economic forces that will affect the pricing of the technology. This is addressed in the next section under Economic Considerations.

7.3 ECONOMIC CONSIDERATIONS

7.3.1 Technology Adoption

New technology (9) is an inevitable part of the information technology industry. The question is not whether new technology is coming, but how fast it will arrive. This is the case with fibre optics for shipboard applications.

The state-of-the-art review of Section 5.2.2 showed that fibre optics is a proven technology that is available today for marine applications.

Although the future is inherently uncertain, knowledge of the fibre optics industry and careful application of technology forecasting can provide insight and assistance with complex decisions.

Crucial to good forecasting is an understanding of the general pattern by which technology is adopted. Usually, a new technology displaces an entrenched old technology - digital for analog switching for example. The plot of the new technology's percentage penetration over time, usually takes the form of S-shaped results, as shown in figure 24A.

Subetitution starts slowly since the new technology is unfamiliar, unproven and expensive. Once the new technology has proven itself and reached about 15% market penetration, its advantages usually turn the tide and substitution becomes rapid as economies of scale come into play.

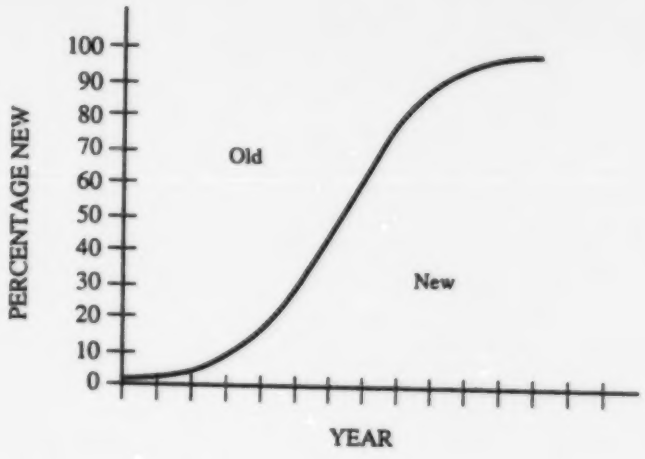
The time from introduction to completion varies among subetitutions, but the pattern usually remains the same. By projecting an on-going trend or using analogies to earlier subetitutions, it is possible to make forecasts.

Figures 24B and 24C show different technology forecast curves for the introduction of fibre optic developments.

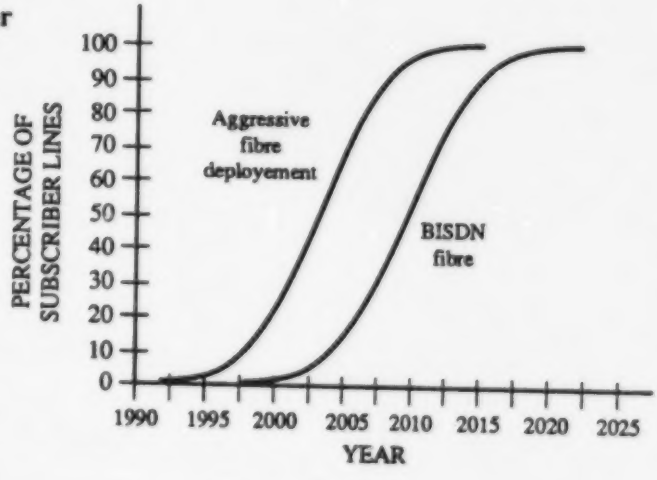
For shipboard applications, the U.S. Navy represents the primary market segment and will influence significantly the development of fibre optic applications. For example, its S-curve could be plotted, covering a 20 year window between years 1990 and 2010.

Figure 24. Fibre optic - Technology forecasts

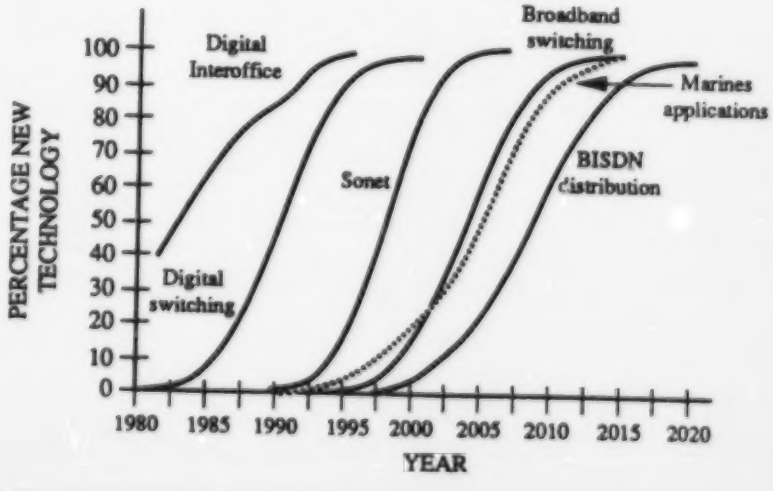
A. The Fisher-Pry model



B. Fibre to the telephone subscriber



C. Overview of some technology forecasts



SOURCE: Technology Future Inc.

7.3.2 *Fibre Optics - Pricing Trends*

As discussed in Chapter 5 on technology issues, two major forces are at work in the marketplace: digital technology and fibre optics. Although digital technology has been steadily adopted since the introduction of T-carrier in the early 1960's, it is fibre optics that is revolutionizing the telecommunications transmission industry.

Optical fibre may already be cost-competitive with copper in some cases, such as for telephone services where new local loops and multiple circuits are needed. As fibre and electronics costs decline as expected, fibre should be more competitive with copper for new telephone loops. If there were not already a copper network in place all-fibre networks would probably be built. Since there is already a copper network, replacing existing copper loops with fibre optics for telephone services alone is likely to be a slow process.

The same analogy could be made for the replacement of existing cabling on board ships with fibre optics. It is easier to consider introducing fibre optics for new ships to be built than by replacing the existing copper cabling on board existing ships. This is likely to be a slow process as well.

According to a recent industry survey (10) of a panel of 64 specialists, which included senior executives of telephone companies and manufacturers of telecommunications equipment and lightwave products, significant advances in electronics and optics have occurred and will produce increased capabilities and reduce costs for telecommunications equipment.

By the year 2000, sharp declines in prices of critical products are expected as shown in Table 27. This will result in significantly lower prices for fibre optic-based systems and make them more attractive for use in marine applications.

Table 27 - Pricing Trends in Fibre Optic Products

Product	Year 2000	Today
Single mode fibre	$ 0.10/meter	$ 0.25 to $ 0.30/m
Multi mode fibre	$ 0.12/meter	$ 0.25 to $ 0.30/m
Packaged laser transmitter	$ 100 each	$ 500 to $ 1 000 each
Packaged lightwave receiver	$ 75 each	$ 250 to $ 500 each
Fibre optic connector	$ 10 each	$ 50 to $ 100 each
Fibre splicing	$ 10/splice	$ 25 to $ 50/splice

Note: Year 2000 pricing is a median forecast expressed in 1988 $ US.

7.3.3 *Trends in Fibre Optic LAN*

The U.S. fibre optic market (11), is expected to grow to a level of $ 1.038 billion in 1990, up from $ 999 million in 1989. Key signs of growth are the development of new types of fibre, expansion in the datacommunication equipment market, and strong indications that fibre is not only moving into the telephone subscriber loop, but also to the desktop. The U.S. fibre optic market can be divided into four applications sectors: telephony, data communications, military and video. This is further divided into eight categories listed in Table 28, which gives a three year projection of market share by application.

Table 28 - U.S. Fibre Optic Market

	(thousands in U.S. $)		
	1988	**1989**	**1990**
Long-haul	6,978	127,990	52,366
Interoffice	71,906	56,722	42,722
Feeder	202,756	213,086	185,610
Dist/Sub	63,885	113,469	265,254
Undersea	35,312	158,289	75,895
Datacom	138,891	179,879	224,947
Military	105,010	126,337	159,771
Video	18,616	23,810	32,159
TOTAL	**763,354**	**999,582**	**1,038,724**

* Source: KMI

The datacommunications market is expected to grow the most, by 30% in 1989 to reach $ 180 million in 1989 and nearly $ 225 million in 1990 or 22% of the U.S. market.

The growth is spurred by the demand for high-speed FDDI systems, for fibre optic in private networks and for more Ethernet systems using fibre.

The military market is expected to grow by 20% in 1989 and by 20% in 1990.

Both markets have a significant influence on the development of fibre optics and products. The marine applications sector will benefit from this level of activity in terms of better products, lower prices, adequate sourcing and support services.

The European market is also considered important and is expected to reach $ 1.7 billion in 1992.

Driving the desktop computer segment of datacommunications or computer-interconnect market will be the all-but-finalized FDDI standard for linking high speed computers for rapid transfer of large quantities of data.

It is predicted that FDDI-based fibre will be the medium of choice to the desktop by the mid-to-late 1990s. The FDDI standard promises to transform fibre optic computer inter-connections to mass-market standard-based products.

Some of the trends involving fibre optic technology are illustrated in Figure 25.

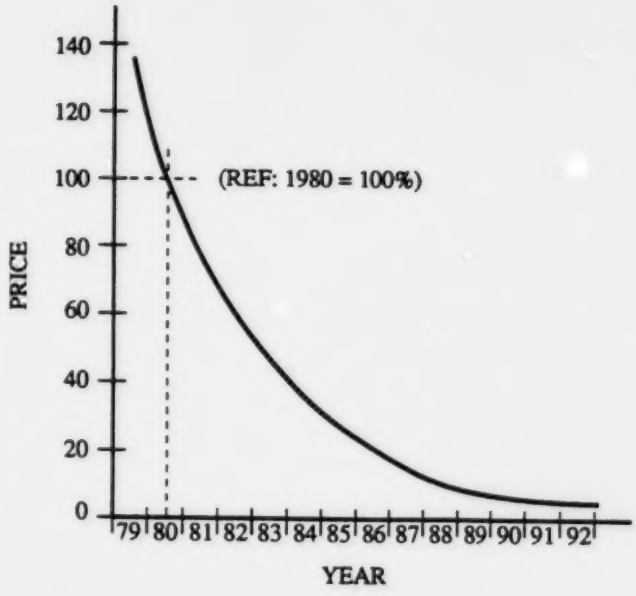
The terminal equipment used for fibre optic communications has dropped dramatically in price in the past few years. This is partly due to increased competition and to decreased parts costs, both electrical and optical. Manufacturers are also making more flexible systems which can be expanded in steps, reducing the initial costs of an installation. The modular systems approach will allow the implementation of fibre optic systems for only slightly higher initial costs than electrical systems, while retaining low cost expansion options.

The advantage of fibre optics for LAN applications is that the medium has unlimited bandwidth and the capacity for future expansion.

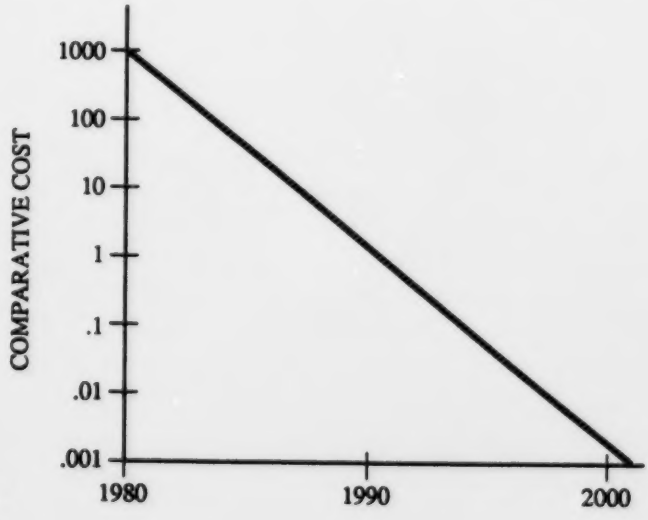
The FDDI standard (to be finalized), the downward pricing trends of equipment, the availability of commercial products and sourcing, the flexibility in the modular system approach implementation, the capacity for future expansion are all factors that make the fibre optic technology attractive for use with a LAN backbone network for shipboard applications.

Figure 25. Fibre optic technology trends

A. Cable fibre price trends



B. Cost per 64Kbps channel



C. Bit rate evolution

DATE	BIT RATE	NO. OF CHANNELS
1980	34 MBPS	500
1983	140 MBPS	2000
1987	560 MBPS	8000
1991	2.4 GBPS	32000
1996	9.6 GBPS	128000

SOURCE: TE&M, September 89

7.3.4 *FDDI - U.S. Government Requirements for Local Area Networks*

The U.S. Government (12) has a wide variety of systems in need of data network consolidation or high performance data transfer. This can also be said of Canadian Government requirements. Until FDDI, network standards such as Ethernet or token ring have not been able to meet the strict requirements imposed by the Government. With FDDI, networks will be produced capable of meeting civilian and military demands. This second generation LAN, in either a backbone or back-end application, will help to keep pace with advancing computer and communications technology.

The U.S. Department of Defense has stringent requirements for LANs because of the sensitive or urgent nature of the data handled. Many federal procurements also require commercially off-the-shelf hardware. This stems from the need to replace equipment quickly and have spares readily available.

Standardization and interoperability are two of the major requirements identified for Government LANs.

This increases the likelihood of having commercially available products, since similar products can be produced by many different vendors. LANs that offer conformance with the emerging FDDI standard will meet the requirements of the U.S. Government.

There are many FDDI integration plans being developed in both the civilian and military sectors of the government. Some of this activity can be seen in the procurement specifications for FDDI-upgradable systems.

The U.S. Navy is embarked on a major fibre optic deployment program with SAFENET II and intends to develop its needs so to be in line with commercial requirements, as opposed to strictly military specifications. This is to assure the U.S. Navy that supply of cable and products will meet the expected increased demand.

The overall effect is a standardization of products, a greater industrial capability to supply the demand requirements of users and an overall decrease in prices expected in the 1990's.

This will certainly have an impact on the development of marine applications, by reducing the requirements to have custom made devices designed specifically for shipboard applications and the overall costs of fibre-based systems.

8. CONCLUSIONS

The major objective of this study was to compare the technical and economical viability of fibre optic technology with existing cabling techniques for a number of specific systems on board the Canadian Coast Guard vessels.

The various technical, financial and economical analyses conducted on the viability of fibre optics for marine applications lead to the following conclusions:

8.1 FINANCIAL CONSIDERATIONS

- For all the fibre optic-based configurations proposed to replace the specific systems evaluated in the study, the estimated incremental costs are higher on average by a ratio of 14 to 1.

- In the short term, the replacement of the existing cabling with fibre optics cannot be justified on costs alone. Other strategic or operational factors will have to be considered to off-set the high initial costs of implementing fibre optic-based systems.

- Substantial fibre optic developments in marine applications are predicted in the 1990's, mostly sponsored by the U.S. Navy. This should have a significant impact on the availability of standard products for shipboard applications and bring about a considerable reduction in costs.

  The mid-to-long term perspective of fibre optics for shipboard use looks good and growth is expected in fibre cabling, with new systems to be introduced by manufacturers.

8.2 TECHNICAL CONSIDERATIONS

- Two systems, the propulsion control system and the video surveillance system, are in the short term, the best candidates for fibre optics implementation.

  In each case, this evaluation is based on the small difference in incremental costs between the fibre optic-based and the copper cabling alternatives.

  In addition, there is a requirement to eliminate certain problems caused by RF interference as in the case of the propulsion control system, which would be solved by using fibre optics.

- Four systems were identified as having good potential for integration with a fibre optic-based LAN backbone system, as part of the ship's infrastructure:

  - the public addressing subsystem;
  - the PBX subsystem;
  - the fire detection system; and,
  - the alarm monitoring and control system.

  This evaluation was based on the characteristics best displayed by these systems and suitability for integration: digital transmission, loop topology and distribution throughout the ship.

- There is a strong industry movement to adopt the Fibre Distributed Data Interface (FDDI) protocol as a standard for the development of fibre optic LAN-based systems.

8.3 GENERAL CONSIDERATIONS

- The use of fibre optics on board ship offers a number of advantages, can solve immediately some of the interference problems and can contribute in the longer term to the thrust in automation and integration envisaged with shipboard systems.

  Some of the advantages of fibre optics identified in the study were:

  - immunity to EMI and RFI (immediate);
  - safety improvement (immediate);
  - weight reduction (for some systems);
  - bandwidth improvement and higher transmission rate;
  - bandwidth availability for future applications;
  - no need to add cabling for future applications, if a backbone network is provided as an infrastructure;
  - integration of some of the ship's functions;
  - automation of some of the ship's functions; and,
  - savings in operational costs (longer perspective).

  Some of the drawbacks identified were:

  - higher complexity;
  - more sensitive systems;
  - specially trained manpower required for installation and maintenance;
  - higher maintenance costs expected in the short term;
  - network management support required for a LAN-based system and system integration;
  - new sets of documentation required, and,
  - development of standards required for use on board ship.

- Fibre optics is a proven technology that is currently used on board ships. It is growing and increasingly is being considered for marine applications.

  However, we believe that the process of replacing the existing systems on board ship by fibre optic-based systems will be a slow one and is more likely to occur with the introduction of new systems by manufacturers that will incorporate fibre optic technology and components.

This has major implications on the development of fibre optic products and systems, sourcing and support services and the reduction in material and equipment prices. The U.S. Navy planned developments in the 1990's are based on the FDDI protocol and will have a significant impact on the use of fibre optic on board ship and the availability of standard interfaces at reasonable prices for shipboard applications.

We believe that FDDI is the most appropriate technology to meet the mid to long term needs of the Canadian Coast Guard for fibre optic-based LAN integrated systems on board their ships.

- More research and development work is required in the development of standards for the use of fibre optic technology on board CCG vessels.

9. RECOMMENDATIONS

Based on the findings of the study, the following recommendations are proposed:

9.1 SHORT TERM CONSIDERATIONS

The Canadian Coast Guard should:

- Consider the use of fibre optics as a replacement for the existing cabling for the propulsion control system and the video surveillance system, as part of the mid-life refit program of a ship.

- Continue promoting the use of the fibre optic technology by:

  - evaluating the technology under different environmental conditions;
  - introducing standards for its use on board ships;
  - developing applications making use of the technology, including the applicability of the LAN FDDI standard for a backbone system and office use.

- Continue influencing the development of standards in this area and monitor Canadian and International work in standard activities for marine applications.

- Consider meeting with major developers of fibre optic-based systems for ships, such as Litton, Unisys and Siemens for example, who manifested a strong interest to meet with the Canadian Coast Guard about the use of fibre optics on board ships.

9.2 MID-TO-LONG TERM CONSIDERATIONS

The Canadian Coast Guard should:

- Consider evolving towards an integrated system approach for shipboard systems.

- Consider introducing a fibre optic backbone system as a standard cabling configuration for future shipboard applications, as part of a mid-life refit strategy and/or for the construction plan of new ships.

- Consider the development of fibre optic-based shipboard applications to be in accordance with the FDDI standard (compatible or upward compatible), for integration to a ship's fibre optic-based LAN backbone network and also readily transportable from one network to another.

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GLOSSARY

A. Fibre Optic Terms

B. Computer Communications Terms

GLOSSARY OF FIBRE OPTIC TERMS

Absorption: That portion of attenuation resulting from conversion of optical power to heat.

Attenuation: The decrease in signal strength along a fibre optic waveguide caused by absorption and scattering. Attenuation is usually expressed in dB/km.

Attenuator: A device that reduces the optical signal by inducing loss.

Bandwidth: The range of frequencies within which a fibre optic waveguide or terminal device can transmit data.

Bending Loss (microbending loss): Attenuation caused by high-order modes radiating from the outside of a fibre optic waveguide. Bending losses occur when the fibre is bent around a restrictive radius.

Bit: The smallest unit of information upon which digital communications are built; also, an electrical or optical pulse that carries this information.

Bit-Error Rate (BER): The fraction of bits transmitted that are received incorrectly.

Buffer: A protective coating applied directly to the fibre.

Cable: One or more optical fibres enclosed within protective covering(s) and strength members.

Cladding: The lower index of refraction material that surrounds the core of an optical fibre, causing the transmitted light to travel down the core.

Connector: A mechanical or optical device that provides a demountable connection between two fibres or a fibre and a source or detector.

Core: The light-conducting central portion of an optical fibre, composed of a material with a higher index of refraction than the cladding.

Coupler: An optical device that combines or splits power from optical fibres.

Cutoff Wavelength: In singlemode fibre, the wavelength below which the fibre ceases to be singlemode.

Decibel (dB): A unit of measurement indicating relative optic power on a logarithmic scale. Often expressed in reference to a fixed value, such as dBm (1 milliwatt) or dBu (1 microwatt).

Detector: The receiving photodiode.

Dispersion: The temporal spreading of a light signal in an optical waveguide, which is caused by light signals travelling at different speeds through a fibre either due to modal or chromatic effects.

Fibre optic Link: A transmitter, receiver and cable assembly that can transmit information between two points.

Fibre optic Power Meter: An instrument that measures the amount of optical power present at the end of a fibre or cable.

Fusion Splicer: An instrument that permanently bonds two fibres together by heating and fusing them.

Graded-Index Fibre: Optical fibre in which the refractive index of the core is in the form of a parabolic curve, decreasing toward the cladding.

ISDN (Integrated Services Digital Network): A set of international technical standards that permit the transmission of voice, data, facsimile, slow-motion video and other signals over the same pair of wires or optical fibres.

Jacket: The outer, protective covering of the cable.

Laser Diode: A semiconductor that emits coherent light when forward biased.

LED (Light-Emitted Diode): A semiconductor that emits incoherent light when forward biased.

Local-Area Network (LAN): A communication link between two or more points within a small geographic area, such as between two buildings.

Loss: The amount of a signal's power, expressed in dB, that is lost in connectors, splices, or fibre defects.

Micrometer: Unit of measurement equals to 1 X 10^{-6} mètre or 1 um.

Mode: A single electromatic wave travelling in a fibre.

Multimode Fibre: An optical fibre that has a core large enough to propagate more than one mode of light (typical diameter is 62,5 micrometers).

Numerical Aperture (NA): The measure of the light-acceptance angle of an optical fibre.

Optical Fibre or Optical Waveguide: A glass or plastic fibre that has the ability to guide light along its axis.

Optical Loss Test Set (OLTS): A source and power meter combined to measure attenuation or loss.

Optical Time Domain Reflectometer (OTDR): An instrument that locates faults in optical fibres or infers attenuation by backscattered light measurements.

Photodiode: A semiconductor device that converts light to electrical current.

Pigtail: A short optical fibre permanently attached to a source, detector or other fibre optic device.

Plastic-Clad Silica (PCS) or Hard-Clad Silica (HCS): A step-index fibre with a glass core and plastic cladding.

Receiver: A terminal device that includes a detector and signal processing electronics. It functions as an optical-to-electrical converter.

Refractive Index: A property of optical materials that relates to the speed of light in the material.

Repeater: A receiver and transmitter set designed to regenerate attenuated signals.

Scattering: The change of direction of light rays or photons after striking small particles. It may also be regarded as the diffusion of a light beam caused by the inhomogeneity of the transmitting material.

Singlemode Fibre: A small-core optical fibre through which only one mode will propagate (typical diameter is 8 micrometers).

Source: A transmitting LED or laser diode, or an instrument that injects test signals into fibres.

Splice: A permanent connection of two optical fibres through fusion or mechanical means.

Step-Index Fibre: Fibre that has a single index of refraction throughout the core.

Subscriber Loop or Local Loop: The link from the telephone company central office (CO) to the home or business (customer premises).

Transmitter: A device that includes a source and driving electronics. It functions as an electro-to-optical converter.

Watts: Linear measurement of optical power, usually expressed in milliwatts, microwatts and nanowatts.

Wavelength-Division Multiplexing: Sending several signals through one fibre with different wavelengths of light.

GLOSSARY - COMPUTER COMMUNICATIONS TERMS

Application Layer: Layer 7 of the OSI model. This layer provides user/applications with access to the SAFENET data transfer system. It also provides a standard set of application service elements.

Asynchronous: Two independent signals with either different phase or frequency, and therefore not occurring precisely together.

Backbone: A high-capacity local area network used to link together a collection of lower capacity local area networks.

Bit Rate: The number of bits transmitted per second.

Broadcast: An unconditional message to all nodes within the system.

Computer Communications Architecture: The structured set of protocols that implement the communication functions for the systems of a networked computer architecture.

Communications Network: The interconnect structure between a collection of communicating computers.

Computer Communications: Cooperative action by the computers in a computer network to support the exchange of application information.

Computer Network: The set of computers interconnected via a communications network.

Concentrator: A device used to implement star-wiring of all or parts of a ring.

Dual Counter-Rotating Ring: Also known as a reversible ring, this is a variation on the basic ring topology in which a second data path, reversed with respect to the first, also links the nodes of the network. This is the approach that has been adopted for SAFENET. The dual ring is a technique for providing fault tolerance.

Fibre Distributed Data Interface (FDDI): The proposed ANSI Standard 100 Mbs token ring that is the basis for SAFENET II. The FDDI standard specifies three distinct protocol layers - Physical Medium Dependent (PMD), Physical (PHY), Media Access Control (MAC) - that conform to the OSI model's Physical layer and the medium-dependent aspects of the Data-Link layer. A fourth component - Station Management (SMT) - controls the overall action of a station to insure its proper operation as a member of the ring.

Fibre Optics: A transmission technology by which modulated lightwave signals, generated by a laser or LED, are propagated along a glass or plastic medium, and then demodulated back into electrical signals by a light-sensitive receiver.

Gateway: A device that interconnects two dissimilar networks, generally performing a protocol conversion across several layers. Also known as Interworking Units in ISO terminology.

Host: The computer system which the communications network is serving. All or part of the layer structure may reside in the host.

Insertion: The electrical or optical introduction of an already physically connected station into the ring.

Interface: A shared boundary between logical or physical components. In the OSI model an interface defines which operations and services a lower layer offers to the one immediately above.

Interoperability: The capability, promoted but not guaranteed by joint conformance with a given set of standards, that enables heterogeneous equipment, generally built by various vendors, to work together in a network environment.

Layer: (1) One of the seven layers of the Open Systems Interconnection (OSI) reference model. (2) A well-defined, logical and hierarchical subdivision of the SAFENET architecture.

Link: (1) A physical, point-to-point transmission path between two nodes. (2) A virtual circuit between two communicating data-link-layer entities.

Local Area Network (LAN): A communications network technology optimized for a moderate size geographic area and characterized by moderate to high data transmission rates, low delay, and low bit error rates.

Medium: The material substance used for the transmission of signals from one point to another.

Message: A generic term describing any information-containing data unit, in an ordered format, sent by means of a communications process from a sender to a receiver. An end-to-end unit of communication. Depending on the protocols utilized, a message may be broken up into one or more frames for transmission.

Network: In SAFENET, the total integrated system, consisting of one or more component subnetworks, that embodies all elements in the OSI.

Network Layer (NL): Layer 3 of the OSI model. This layer provides upper layers with independence from the actual delivery of data between end systems through the intervening network structure.

Network Management: The collection of administrative structures, policies and procedures which collectively provide for the management of the organization and operation of the network as a whole.

Node: An essentially topological term, often used interchangeably but incorrectly with the terms host and station, denoting the points at which devices attach to a medium.

Octet: A unit of information consisting of eight contiguous bits.

Open Systems: Denoting the ability of any two systems conforming to the OSI Reference Model and associated standards to interconnect.

Open Systems Interconnection (OSI): This term specifically refers to the International Standards Organization Basic Reference Model of Open Systems Interconnection. This reference model is the basis of a set of international standard protocols which allow a conforming system to interconnect and exchange data with all other systems obeying the same standards.

Physical Layer: Layer 1 of the OSI model. the physical layer provides the functional and procedural means to activate, maintain and deactivate physical connections for bit-transmission between data-link entities.

Presentation Layer: Layer 6 of the OSI model. The presentation layer provides independence to the application processes from differences in data representation as well as enhanced data transfer services such as encryption and compression.

Primary ring: In the dual-ring topology, that ring which has been designated a-priory as the sole carrier of application traffic in the normal configuration.

Protocol: The rules and conventions under which interactions over the network between peer entities are carried out. The set of rules governing the exchange of data between two entities. A protocol is precisely defined in terms of the format of the PDU's exchanged between entities, the semantics of each field in each PDU, and the allowable sequencing of protocol actions.

Real Time: A Real Time event or data transfer is one which must be accomplished within an allotted amount of time or the accomplishment of the action has either no or diminishing value. The value of the data or accomplishment of the event is constant within the time limit.

Relay: When two systems are not connected directly to each other, and connectivity is through an intermediary, the intermediary is known generically in ISO terminology as a «relay».

Ring: A local network topology in which stations are attached to repeaters connected in a closed loop. Data is transmitted in one direction around the ring, and can be read by all attached stations.

Route: A path from one address to another in a network or internet.

SAFENET: This acronym, standing for Survivable, Adaptable, Fibre-Optic Embedded NETwork, is the term used to identify a family of local area network (LAN) standards that is being developed for real-time military data exchange applications. SAFENET is a joint Industry/Navy endeavour that is sponsored by the Space and Naval Warfare Systems Command (SPAWAR).

SAFENET I: The first member of the SAFENET family of LAN standards. SAFENET I is based on the IEEE 802.5 token-ring and incorporates protocols for both ISO compatibility and for real-time (minimal latency) performance.

SAFENET II: The second member of the SAFENET family of LAN standards. SAFENET II is based on the FDDI token-ring.

Segment: An individual local network. In SAFENET, a single, distinct physical ring.

Session Layer: Layer 5 of the OSI model. The session layer provides a basic set of control and coordination services for application processes, including dialog control, synchronization, resynchronization and activity management.

Star-Wired Ring: A combination of the physical wiring of a star network and the logical flow of data of a ring.

Systems Management: Functions in the application layer related to the management of various OSI resources and their status across all layers of the architecture.

Sublayer: A subdivision of a layer.

Subsystem: In OSI terminology, the intersection of an individual system with a layer. Each system itself is viewed as being logically composed of a succession of subsystems.

SubLAN: A LAN segment, e.g., a single ring.

Subnetwork: A set of one or more intermediate open systems which provide relaying and through which an open system may establish network connections. A subnetwork is a representation within the OSI model of a real network. A single SAFENET subLAN can be considered a subnetwork.

System: A user-defined set of one or more computers, the associated software, peripherals, terminals, human operators, physical processes, information transfer means, etc., that forms an autonomous whole capable of performing information processing and capable of executing defined protocols. In short, a system is a device connected to a network at a node that hosts one or more users and can engage in communications with other network systems.

Throughput: The total useful information processed or communicated during a specified time period.

Token: A control signal comprised of a unique signalling sequence that circulates on a token ring. It is the means by which the authority to transmit is passed from one station to another.

Token Ring: (1) A medium access control technique for rings. A token circulates around the ring. A station may transmit by seizing the token, inserting a packet onto the ring, and then retransmitting the token. (2) A term denoting a Local Area Network based on the token-ring technique.

Topology: The way in which the stations are attached to a network or interconnected.

Transmission Speed: The rate at which encoded bit information is applied to a medium by a sending node, typically expressed as a baud rate. The 100 Mbs FDDI system, which uses the 4B/5B encoding technique, requires a transmission speed of 125 megabaud.

Transport Layer: Layer 4 of the OSI model. This layer provides reliable, transparent transfer of data between endpoints.

Upstream Station: The station in a ring which, relative to the direction of the signal flow, immediately precedes a given station.

User: The ultimate user of the network.

APPENDIX A

TERMS OF REFERENCE OF THE STUDY

TRANSPORTATION DEVELOPMENT CENTRE

STATEMENT OF WORK

SHIPBOARD FIBRE OPTICS

February, 1989

1. INTRODUCTION

The Telecommunications and Electronics Directorate (T&E) of the Canadian Coast Guard (CCG) have identified the need to compare fibre optic technology with conventional cabling techniques for specific shipboard applications.

Given that ship building activities are continuously occurring and that major refits of existing vessels are planned where much of the navigation, communication and monitoring/control systems are to be upgraded, this comparative study will ensure the best networking alternative is selected.

It is expected that the potential integration benefits (i.e. combining several communication/control functions) of the fibre alternative will impact the ship automation thrust of TDC's marine R&D program. Consequently, the fibre integration issue will be examined in this light.

2. MODAL OBJECTIVE (M300)

Address technological problems or issues relating to conventional marine operations in Canadian waters or with Canadian vessels or equipment.

3. MODAL SUB-OBJECTIVE (M333)

Improve the safety, efficiency and performance of government and commercial vessels and marine structure operating from Canadian and international waters.

4. PROJECT OBJECTIVE

To conduct a comparative study concerning the use of fibre optics and conventional cabling on-board CCG vessels, with a view to reducing capital investment , maintenance costs and the risk of RF interference while improving performance and bandwidth.

5. SCOPE

The activities proposed under this project will involve an investigation of the existing communication media for specific shipboard applications. For each specified application, the conventional cabling approach will be compared to a fibre optic alternative. The cost, performance and operational data will be compared in each case, as well as the potential to integrate some of the communication systems and other applications. The best alternative will be recommended as per the above criteria and the technology that offers a potential for unified ship control.

6. DETAILED STATEMENT OF WORK

6.1 Develop a detailed work plan, activity schedule, cash flow projections, project management control and documentation procedures, within three (3) weeks of the effective start date. Submit to TDC for review and approval.

6.2 Initial kickoff meeting.

6.3 Survey the requirements for point-to-point type and other networks on-board CCG vessels Target application areas include the speed log and gyrocompass navigation systems, video surveillance, and internal communication systems. Use the Vessel Survey Analysis for Fibre Optic Implementation as a point of departure. (This document can be obtained at TDC premises)

6.4 Conduct a comparative study between conventional twisted-shielded pair/coaxial/4-wire media and the fibre alternative (analog or digital) taking into account the economic, performance and operational issues.

6.5 Investigate the potential to integrate the systems listed in 6.3 as a result of the increased bandwidth availability. Study the interfacing issues related to each application and comment on the likelihood of integrating fibre optic electronics with the existing terminal equipment.

6.6 Prepare recommendations towards the use of fibre optic communication media on-board CCG vessels in the designated application areas.

6.7 Prepare a report documenting the comparative study and deliver an informal presentation of the findings to TDC and CCG personnel. The location for this presentation is tentatively scheduled for the Montreal area.

6.8 The deliverables include monthly progress reports as well as the final report.

7. PROJECT ADMINISTRATION

The Executive Director, Transportation Development Centre (TDC) will appoint a Project Officer, who will be the scientific authority to manage the project on behalf of TDC. He will be supported by representatives from the T&E directorate. Contract administration will be provided by Supply and Services Canada (DSS).

8. PROJECT CONTROL

The project shall be controlled by a CPM, PERT, SPEC or equivalent responsibility assignment and scheduling method. It is requested that the contractor utilize PC-based project management tools. Project management updates as well as the monthly progress reports should be communicated to the project officer via electronic mail.

Budgets and schedules for each project element should be prepared at the start of the project and monitored regularly to ensure that the resources available are compatible with the estimates to complete the work.

9. REPORTING REQUIREMENTS

9.1 Progress Reports

To facilitate the management of the project, a minimum of five (5) copies of the progress reports shall be submitted on a monthly basis to the TDC Project Officer, with a copy to the DSS science procurement officer. These reports shall be short and concise, not exceeding two typewritten pages.

The format of the progress report should be as follows: -

9.1.1 A list of all persons actively engaged on the project and their functions.

9.1.2 Current status of the work, containing:
- a) an estimate of the percentage of work completed;
- b) the percentage of time elapsed; and
- c) whether the project will be completed within the established schedule and the agreed financial limitation.

9.1.3 Work accomplished since the period last reported.

9.1.4 Problem areas.

9.1.5 Work to be addressed in the coming months.

9.1.6 Action required to be undertaken by TDC.

9.1.7 Contact made with outside agencies or companies, or major visits planned in connection with the project. The contractor is required to identify and record names and addresses of individuals or organizations. Such names may be of use to disseminate information at the end of the contract.

9.2 Publication Standards

All reports with the exception of progress reports and interim reports shall be prepared for publication in accordance with the "TDC Publication Standards and Guidelines for Contractors (TP 929)", (the latest issue to be provided to the contractor by the DSS Science Procurement Manager at the contract negotiation stage) and are thus subject to the following requirements:

9.2.1 Reports will be assigned a TP number by TDC.

9.2.2 Metric units (S.I.) shall be used in all reports. (Unless special exception is warranted).

9.2.3 Reports shall be prepared in English or French.

9.2.4 Reports must include a summary in English and French, either as a section in the report or as a separate document (see TP 929, section 3.7).

9.2.5 A bilingual Report Documentation Form (RDF) shall be included in every report as specified in TP 929, Section 3.4. Blank forms (see TP 929, Appendix A) will be supplied by TDC.

9.2.6 Translation shall be provided in the case of:
- a) the RDF by TDC.
- b) the summary by TDC.

9.3 Publication Schedule

9.3.1 Reports shall be submitted in accordance with the following:

a) 5 copies each of draft reports (English or French), including a bilingual summary section; Report Documentation Form (English or French); delivered seven (7) months after contract signing date.

b) TDC comments on draft reports to contractor within four (4) weeks after receipt.

c) 30 copies of final published reports in English delivered four (4) weeks after receipt of TDC's comments.

d) All reports with the exception of progress and interim reports shall be accompanied by a camera-ready master suitable for reproduction.

9.3.2 For control purposes, all reports, except progress reports, shall be delivered to:

Office Services Supervisor
Transportation Development Centre
200 Rene Levesque Blvd. West
Suite 601, West Tower
Montreal, Quebec H2Z 1X4

The Records Office will ensure that copies are forwarded to the project officer.

APPENDIX B

COST CALCULATION TABLES

Table 5. Public addressing system - Copper installation
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS
CABLE 2 PAIRS #18 (BELDEN 9368)	4440m	$3	$13 320	BELDEN 9368
JUNCTION BOXES (margin)	10	N/A	-	•
SPEAKER HOUSING (margin)	60	N/A	-	•
SUBTOTAL MATERIALS			**$13 320**	
LABOUR (INCREMENTAL COSTS)				
CROSS CONNECTS	N/A	N/A	-	•
CABLE PULLING	N/A	N/A	-	•
TESTING	36mhrs	$60	$2 160	
BULKHEAD PENETRATIONS	N/A	N/A	-	•
SUBTOTAL LABOUR			**$2 160**	
TOTAL FIBRE SUBSYSTEM			**$15 480**	

* NO INCREMENTAL COST

Table 6. Public addressing subsystem - Fibre one-to-one replacement
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS
FIBRE TRANSMITTER	7	$4 000	$28 000	MODIFIED SUHNER 9845.23
COUPLER	60	$125	$7 500	CANSTAR MC3-C-62.5
WDM	45	$642	$28 890	JDS 813
FO/SPKR INTERFACE (TLK-BCK)	45	$1 500	$67 500	SUHNER 9845.23
FO/SPKR INTERFACE	15	$700	$10 500	SUHNER 9845.23
FO CABLE	4440m	$10	$44 400	OPTICAL CABLE HYBRID
JUNCTION BOXES	10	$1 000	$10 000	
SPEAKER HOUSING	60	$100	$6 000	
SUBTOTAL MATERIALS			**$202 790**	
LABOUR (INCREMENTAL COSTS)				
SPLICES	240	$15	$3 600	
CROSS CONNECTS	N/A	N/A	-	*
CABLE PULLING	N/A	N/A	-	*
TESTING	72mhs	$60	$2 880	
BULKHEAD PENETRATIONS	N / A	N/A	-	*
SUBTOTAL LABOUR			**$7 920**	
TOTAL FIBRE SUBSYSTEM			**$210 710**	

* NO INCREMENTAL COST

Table 7. PBX subsystem - Copper installation
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS
CABLE 2 PAIRS #18 (BELDEN 9368)	2280m	$3	$6 840	BELDEN 9368
JUNCTION BOXES	1	N/A	-	*
TELEPHONE HOUSING	60	N/A	-	*
TELEPHONES	38	N/A	-	*
DIGITAL PBX	1	N/A	-	*
SUBTOTAL MATERIALS			**$6 840**	
LABOUR (INCREMENTAL COSTS)				
CROSS CONNECTS	N/A	N/A	-	*
CABLE PULLING	N/A	N/A	-	*
TESTING	23mhrs	$60	$1 380	
BULKHEAD PENETRATIONS	N/A	N/A	-	*
SUBTOTAL LABOUR			**$1 380**	
TOTAL SUBSYSTEM COSTS			**$8 220**	

* NO INCREMENTAL COST

Table 8. PBX subsystem - Fibre one-to-one replacement
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS
FIBRE INTERFACES	76	$1 500	$114 000	TO BE DEVELOPPED
FO CABLE	2280m	$10	$22 800	OPTICAL CABLE HYBRID 2 FIBRE
JUNCTION BOXES	1	$6 000	$6 000	MAIN DISTR. FRAME
TELEPHONE HOUSING	38	$100	$3 800	
SUBTOTAL MATERIALS			**$146 600**	
LABOUR				
SPLICES	76	$15	$1 140	
CROSS CONNECTS	N/A	N/A	-	*
CABLE PULLING	N/A	N/A	-	*
TESTING	46mhs	$60	$2 760	
BULKHEAD PENETRATIONS	N / A	N/A	-	*
SUBTOTAL LABOUR			**$3 900**	
TOTAL SUBSYSTEM			**$150 500**	

* NO INCREMENTAL COST

Table 9. TV entertainment system - Copper installation
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS
CABLE (RG-59) (BELDEN 9240)	2000m	$3	$6 000	BELDEN 9240
SPLITTER (margin)	48	N/A	-	*
CONNECTORS	60	N/A	-	*
TV SETS	48	N/A	-	*
CHANNEL AMPLIFIERS	14	N/A	-	*
MISCELLANEOUS		N/A	-	*
SUBTOTAL MATERIALS			**6 000$**	
LABOUR (INCREMENTAL COSTS)				
CROSS CONNECTS	N/A	N/A	-	*
CABLE PULLING	N/A	N/A	-	*
TESTING	58mhrs	$60	$3 480	
BULKHEAD PENETRATIONS	N/A	N/A	-	*
SUBTOTAL LABOUR			**$3 480**	
TOTAL SUBSYSTEM COSTS			**$9 480**	

* NO INCREMENTAL COST

Table 10. TV entertainment system - Fibre one-to-one replacement
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS
FIBRE TRANSMITTER	2	$15 000	$30 000	CATEL 30 CHANNEL
FO CABLE	2000m	$8	$16 000	BELDEN 225422
COUPLERS	48	$125	$6 000	CANSTAR
CONNECTORS (AT&T ST)	144	$80	$11 520	AT & T ST
RECEIVERS	48	$10 000	$480 000	CATEL 30 CHANNEL
TV SETS HOUSINGS (margin)	48	$300	$14 400	
AMPLIFIERS	14	N/A	-	•
			$557 920	
SUBTOTAL MATERIALS				
LABOUR (INCREMENTAL COSTS)				
SPLICES	144	$15	$2 160	
CROSS CONNECTS	N/A	N/A	-	•
CABLE PULLING	N/A	N/A	-	•
TESTING	29mhrs	$60	$1 740	
BULKHEAD PENETRATIONS	N/A	N/A	-	•
SUBTOTAL LABOUR			$3 900	
TOTAL FIBRE SUBSYSTEM			**$561 820**	

• NO INCREMENTAL COST

Table 11. Propulsion control system - Copper installation
Incremental costs

	QTY	UNIT COST	TOTAL COST	COMMENTS
CABLE # 16, 2 PAIRS	3 500m	$3	$10 500	ALPHA #1085
CABLE PULLING	N/A	N/A	.	*
TESTING	N/A	N/A	.	*
BULKHEAD PENETRATION	N/A	N/A	.	*
TOTAL			$10 500	

* NO INCREMENTAL COST

Table 12. Propulsion control system - Fibre one-to-one replacement
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS
FIBRE CABLE	200m	$11	$2 200	OPTICAL CABLE 4 FIBRES
RS-422 FIBRE INTERFACES	20	$100	$2 000	
ELECTRICAL INTERFACE	6	$1 000	$6 000	
ENCLOSURES	8	$500	$4 000	
SUBTOTAL MATERIALS			$14 200	

LABOUR (INCREMENTAL COSTS)				
SPLICES	44	$15	$660	
CABLE PULLING	N/A	N/A	.	*
CROSS CONNECTS	N/A	N/A	.	*
TESTING	42mhrs	$60	$2 520	
SUBTOTAL LABOUR			$3 180	
TOTAL			$17 380	

* NO INCREMENTAL COST
BASED ON 34 TERMINAL TESTING POINTS

Table 13. ***Fire*** **detection system - Copper installation**
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS
CABLE #16 (BELDEN 9366)	2000m	$3	$6 000	
SMOKE DETECTORS	180	N/A	-	•
TEMPERATURE SENSORS	80	N/A	-	•
PULL SWITCHES	20	N/A	-	•
CONTROLLER	1	N/A	-	•
SUBTOTAL MATERIALS			**$6 000**	
LABOUR (INCREMENTAL COSTS)				
CROSS CONNECTS	N/A	N/A	-	•
CABLE PULLING	N/A	N/A	-	•
TESTING	168mhrs	$60	$10 080	
BULKHEAD PENETRATIONS	N/A	N/A	-	•
SUBTOTAL LABOUR			**$10 080**	
TOTAL SUBSYSTEM COSTS			**$16 080**	

* NO INCREMENTAL COST

Table 14. Fire detection system - Fibre one-to-one replacement
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS
FIBRE TRANSCEIVER	24	$100	$2 400	THOMAS & BETTS RS-422
FO CABLE	2000m	$10	$20 000	OPTICAL CABLE HYBRID 2 FIBRES
COUPLERS	560	$125	$70 000	CANSTAR MC3-C-62.5
CONNECTORS (AT & T ST)	560	$80	$44 800	AT & T ST
RS-422 FO-MODEMS	280	$100	$28 000	THOMAS & BETTS RS-422
JUNCTION BOXES (margin)	28	$1 000	$28 000	
SENSOR HOUSING	280	$80	$22 400	TO BE DEVELOPPED
SUBTOTAL MATERIALS			**$215 600**	
LABOUR				
SPLICES	1400	$15	$21 000	
CROSS CONNECTS	N/A	N/A	-	*
CABLE PULLING	N/A	N/A	-	*
TESTING	336mhrs	$60	$20 160	
BULKHEAD PENETRATION	N/A	N/A	-	*
SUBTOTAL LABOUR			**$41 160**	
TOTAL			**$256 760**	

* NO INCREMENTAL COST

Table 15. Alarm monitoring & control system (Backbone) - Copper installation Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS
CABLE #14 (BELDEN 8720)	1000m	$3	$3 000	BELDEN 8720
LSU	12	N/A	-	*
SENSORS	375	N/A	-	*
CABLE FOR SENSORS	10 500m	N/A	-	*
SUBTOTAL MATERIALS			$3 000	
LABOUR				
CABLE PULLING	40mhrs	$60	$2 400	
TESTING	8mhrs	$60	$480	
SUBTOTAL LABOUR			$2 880	
TOTAL			$5 880	

* NO INCREMENTAL COST

Table 16. Video surveillance system - Copper installation
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS
CABLE (RG-59) (BELDEN 9240)	100m	$3	$300	BELDEN 9240
SPLITTERS (margin)	2	N/A	-	*
CONNECTORS	2	N/A	-	*
TV SETS	1	N/A	-	*
CAMERA AND SERVO MOTOR	1	N/A	-	*
SUBTOTAL MATERIALS			**$300**	
LABOUR (INCREMENTAL COSTS)				
CROSS CONNECTS	N/A	N/A	-	*
CABLE PULLING	N/A	N/A	-	*
TESTING	2mhrs	$60	$120	
BULKHEAD PENETRATIONS	N/A	N/A	-	*
SUBTOTAL LABOUR			**$120**	
TOTAL SUBSYSTEM COSTS			**$420**	

* NO INCREMENTAL COST

Table 17. Video surveillance system - Fibre one-to-one replacement
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS	
FIBRE TRANSCEIVER	1	$600	$600	HUBER SUHNER	
FO CABLE	100m	$10	$1 000	OPTICAL CABLE HYBRID	
COUPLERS	0	$125	$0	CANSTAR	
CONNECTORS (AT & T ST)	6	$80	$480	AT & T	
RECEIVERS	1	$700	$700	SUHNER	
HOUSING	2	$700	$1 400	HAMMOND	
RS-422 MODEM	2	$100	$200	THOMAS & BETTS	
SUBTOTAL MATERIALS			**$4 380**		
LABOUR					
SPLICES	4	$15	$60		
CROSS CONNECTS	N/A	N/A	-	•	
CABLE PULLING	N/A	N/A	-	•	
TESTING	4mhrs	$60	$240		
BULKHEAD PENETRATION	N/A	N/A	-	•	
SUBTOTAL LABOUR			**$300**		
TOTAL			**$4 680**		

• NO INCREMENTAL COST

Table 18. Gyrocompass system - Copper installation
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST
CABLE #14 (BELDEN 8720)	600m	$3.50	$2 100
CABLE PULLING	N/A	N/A	-
TESTING	8mhrs	$60	$480
TOTAL			**$2 580**

Table 19. Gyrocompass system - Fibre one-to-one installation
Incremental costs

MATERIALS

	QTY	UNIT COST	TOTAL COST	COMMENTS
CABLE 2 FIBRES OPTIC CABLE HYBRID	200m	$10	$2 000	OPTICAL CABLE TYPE B
FIBRE INTERFACE TX	14	$2 000	$28 000	TBD
FIBRE INTERFACE RX	14	$1 500	$21 000	TBD
HOUSINGS	15	$1 000	$15 000	TBD
SUBTOTAL			$66 000	

LABOUR

SPLICES	28	$15	$420	
CABLE PULLING	N/A	N/A	-	
TESTING	16mhrs	$60	$960	
SUBTOTAL			$1 380	
TOTAL COST			$67 380	

Table 20A. Public addressing subsystem - Fibre integrated network
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST
AUDIO TX	10	$2 000	$20 000
AUDIO TX / RX	20	$3 000	$60 000
LABOUR	108mhrs	$60	$6 480
SUBTOTAL			$86 480

Table 19. Gyrocompass system - Fibre one-to-one replacement
Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST	COMMENTS
CABLE 2 FIBRES OPTIC CABLE HYBRID	200m	$10	$2 000	OPTICAL CABLE TYPE B
FIBRE INTERFACE TX	14	$2 000	$28 000	TBD
FIBRE INTERFACE RX	14	$1 500	$21 000	TBD
HOUSINGS	15	$1 000	$15 000	TBD
SUBTOTAL			**$66 000**	
LABOUR				
SPLICES	28	$15	$420	
CABLE PULLING	N/A	N/A	-	
TESTING	16mhrs	$60	$960	
SUBTOTAL			**$1 380**	
TOTAL COST			**$67 380**	

Table 21. Fire detection system - Fibre integrated network (Existing sensors) Incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST
CABLE	200m	$3	$600
SENSOR INTERFACES	12	$4 000	$48 000
HOUSINGS	12	$300	$3 600
LABOUR	200mhrs	$60	$12 000
TOTAL			$64 200

Table 22. Fire detection system - Fibre integrated network (Optic sensors)
Incremental costs

MATERIALS

	QTY	UNIT COST	TOTAL COST
FIBRE CABLE (2FIBRES)	5 600	$8	$44 800
SMOKE SENSORS	180	$300	$54 000
THERMIC SENSORS	80	$300	$24 000
PULL STATION	20	$100	$2 000
FDDI INTERFACE	12	$4 000	$48 000
LABOUR	380mhrs	$60	$22 800
TOTAL			$195 600

Table 23. Alarm monitoring & control system - Fibre integrated network (Existing sensors) Incremental costs

MATERIALS

	QTY	UNIT COST	TOTAL COST
SENSOR INTERFACES	12	$4 000	$48 000
HOUSINGS	12	$300	$3 600
LABOUR	224mhrs	$60	$13 440
TOTAL			$65 040

Table 24. Alarm monitoring & control system - Fibre integrated network (Optic sensors) Incremental costs

MATERIALS

	QTY	UNIT COST	TOTAL COST
SENSORS	375	$300	$112 500
SENSOR INTERFACES	12	$2 000	$24 000
CENTRAL CONTROL	1	$20 000	$20 000
FIBRE CABLE (BELDEN 225432)	7 500	$8	$60 000
HOUSINGS	375	$200	$75 000
LABOUR	420mhrs	$60	$25 200
TOTAL			$316 700

Table 25. Fibre integrated network
Summary of incremental costs

MATERIALS	QTY	UNIT COST	TOTAL COST
BACKBONE LAN:			
FDDI NODE	12	$15 000	$180 000
HOUSING & JUNCTION BOXES	12	$2 000	$24 000
CABLE (MM 62.5 / 125)	1000m	$11	$11 000
CONNECTORS & SPARES	100	$80	$8 000
LABOUR	40mhrs	$60	$2 400
SUBTOTAL			$225 400
SUBSYSTEMS			
PA SUBSYSTEM			$86 480
PBX SUBSYSTEM			$33 000
FIRE DETECTION SYSTEM			$64 200
ALARM & MONITORING SYSTEM			$65 040
SUBTOTAL			$348 720
TOTAL COST			$474 120

APPENDIX C

LIST OF PERSONS AND COMPANIES CONTACTED

1. Warren Wise, Worldmald (fire detection system)
2. Anne Talvitie, Unisys Toronto (gyrosystem)
3. Mike Snodgrass, Unisys USA (fibre optic components)
4. Eugene Matlashewski, Unisys Winipeg (shinpads)
5. R.Y. Guimond, Unysis Winipeg (shinpads)
6. Edward Vuhar, Unisys Toronto (shinpads)
7. Joe Wolszyn, United Marine (integrated communications system)
8. Robert Marais, Ingalls Shipbuilding (alarm monitoring and control system)
9. Bill Sierra, Litton Systems (fibre optic sensors and components)
10. Emery L. Moore, Litton Systems (fibre optic sensors and components)
11. Vance Saige, Planning Systems (fibre optics engineering)
12. Richard Fairman, Newport News Shipbuilding (shipbuilders)
13. Richard Bailly, Vitro Corporation (fibre optic components)
14. Teresa Pearson, Interphase (safenet, FDDI components)
15. Cam Massie, Canada Wire & Cable (installation of FO systems)
16. Richard Steinberger, Martin Marietta (Safenet II products)
17. Carrie McCauley, Optech (fibre sensors)
18. Bill Sorochina, AT&T Fibre Division (fibre optic cable & connectors)
19. Rae Woods, AT&T Fibre Division (fibre optic cable & connectors)
20. Robin Jones, Je Fanic (Genius - LAN)
21. Baby Hedrick, Optical Cable Corporation (fibre cable for marine)
22. Tom Wren, Hirshman (WDM, Connectors)
23. Terry Crofit, Burld Industries (video surveillance system)
24. Angie Dereschewitz, Canstar (WDM, connectors)
25. Arnold Bass, Dynasty, Suhner (cable)
26. Commander J.A. Thatcher, DND, Ottawa (Shinpads)
27. Cptn. Thomas F. Brown, DND (Shinpads)
28. Mike Keast, DND (Shinpads)
29. Ken Tang, DND (Shinpads)
30. Harry Jang, CCG Dartmouth (Ethernet LAN)
31. Mr. E.C. Anderson, CCG, HQ
32. Commander Rex Buddenbeg, U.S. CG. (gral)
33. Arc Justice U.S. Navy (gral)
34. Les Brown, Canadian General Electric (cycloconverters)
35. J. Hensler, German & Milner (cycloconverters)
36. Jon Turley, Area Brown Bovery (propulsion control system)
37. Peter Richardson, Siemens, Montreal (marine automation)
38. Klaus N. Wilk, KWA (internal communications system)
39. Bill Fawcett, Marconi Canada (TV entertainment system)

40. Aget Sodhi, Securiplex (fire alarm system)
41. John Beckett, Racal - Decca (monitoring control system)
42. Greg Font, Honeywell Optoelectronics (fibre optic sensors for military application)
43. Norris Lewis, Litton Polyscientific (fibre optic products)
44. Paul Mangano, Smiths Industries (gyroscope)
45. J. Lawrence, Precision Products DM, Northrop Corporation (gyroscope)

APPENDIX D

LITERATURE SURVEY

Comparative Study - Shipboard Fibre Optics

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